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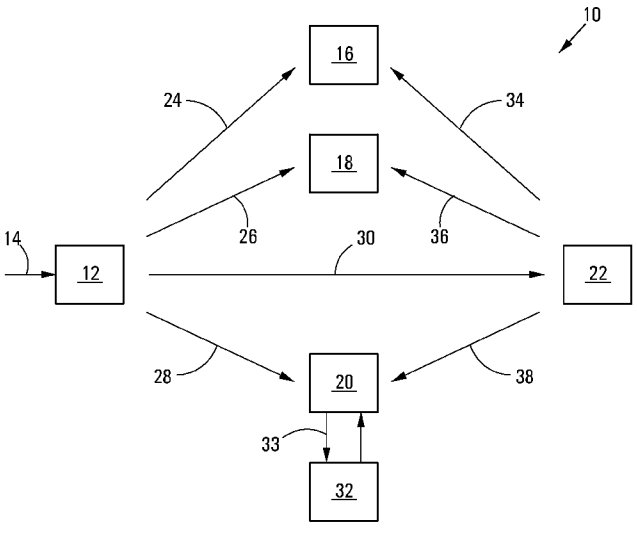


FIG 1

(57) Abstract: A prawn production installation for the intensive production of prawns includes at least one seawater purification installation for the purification of incoming seawater, one or more acclimation tanks, one or more raceways provided with circulation means for circulating water in the raceways at a rate of about 3-9 cm/sec, one or more grow-out tanks and at least one water treatment installation for treating water from the grow-out tanks. The or each water treatment installation has at least one anaerobic treatment zone and at least one aerobic treatment zone and at least the acclimation tanks, the raceways and the grow-out tanks are housed in closed structures.

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A METHOD FOR THE INTENSIVE PRODUCTION OF PRAWNS

This invention relates to a method and an installation for the intensive production of prawns.

Prawn aquaculture today is considered to be a young science. Routine genetic selection has only been recently conducted, and in many areas of the world the collection of wild broodstock is still relied on for the production of post-larval prawns. In parts of the world, prawns are also referred to as shrimp. At present, prawn aquaculture is largely carried out in the open air in ponds and the industry has been faced with the challenges of variable and often low production per unit area, disease, poor nutrition and lack of control over the culture environment. This has periodically resulted in major losses. The method and installation of the present invention result in the stable production of large prawns on a large scale.

According to a first aspect of the invention there is provided a prawn production installation for the intensive production of prawns, the production installation including

at least one seawater purification installation for the purification of incoming seawater;

one or more acclimation tanks;

one or more raceways provided with circulation means for circulating water in the raceways at a rate of about 3-9 cm/sec, and preferably about 5-7 cm/sec;

one or more grow-out tanks; and

at least one water treatment installation for treating water from the grow-out tanks, the or each water treatment installation having at least one anaerobic treatment zone and at least one aerobic treatment zone;

at least the acclimation tanks, the raceways and the grow-out tanks being housed in closed structures.

The closed structures may be greenhouses. The greenhouses may be provided with retractable radiation barriers for conserving heat. The barriers may be in

the form of reflective sheeting. The means for circulating water in the raceways may be provided by one or more motor driven paddlewheels.

Preferably, the at least one seawater purification installation, the one or more acclimation tanks, the one or more raceways, the one or more grow-out tanks and the at least one water treatment installation for treating water from the grow-out tanks will all be housed in greenhouses.

The greenhouses will preferably be provided with sanitizing stations such as footbaths for workers to maintain biosecure conditions for prawn production. The optimum temperature of the water for prawn growth is about 27-31°C and can be maintained through the use of immersion heaters and solar radiation. The Applicant has found that enclosing the raceways and tanks in greenhouses, and providing the greenhouses with retractable radiation barriers, reduces heat loss and aids in reducing the amount of energy required for heating. Heating culture water in tanks for prawn production can be the highest variable cost for prawn production in non-tropical areas.

The acclimation tanks may have volumes of about 1,6m^3. The raceways may have volumes of about 280m^3. The grow-out tanks may have volumes of about 1500m^3. Naturally, smaller or larger tanks and raceways may be used depending on circumstances. Dividing the prawn growth cycle into three stages and locating the acclimation tanks, raceways and grow-out tanks in greenhouses, resulted in the efficient utilization of space.

The prawns may be selected from species such as *Litopeneaus vannamei, L. monodon, L. chinensis, and L. stylirostris.* Preferably, the prawns will be *L. vannamei.*

The prawn production installation may include an algae culture installation for culturing algae. In an embodiment of the invention, the algae culture facility was constructed adjacent to the acclimation tanks and nursery raceways to produce the nutritious algae species which complemented the prawn diet. A water quality laboratory was included in the installation to insure adequate environmental conditions for prawn health and good growth. Wall-mounted YSI (Yellow Springs Instruments) panels were

located within the greenhouses near all tanks and raceways for regular inspection by prawn production workers to monitor dissolved oxygen (DO), temperature and pH. Paddlewheels and disc diffusers were used to circulate and aerate water in raceways while paddlewheel aerators and vertical pump aerators were used in the larger grow-out tanks. Filtration and aeration in acclimation greenhouses was achieved through the use of disc diffusers and mechanical and biological filters.

According to a second aspect of the invention there is provided a prawn production installation for the intensive production of prawns, the production installation including

at least one seawater purification installation for the purification of incoming seawater;

one or more acclimation tanks;

one or more raceways provided with circulation means for circulating water in the raceways;

one or more grow-out tanks;

at least one water treatment installation for treating water from the grow-out tanks,

at least the acclimation tanks, the raceways and the grow-out tanks being housed in closed structures, the or each grow-out tank having circulation means for circulation water in the grow-out tank, a centrally positioned drain opening, a bottom which slopes inwardly towards the drain opening and a flushing mechanism for perodically flushing a volume of water through the drain opening.

According to a third aspect of the invention, there is provided a method for the intensive production of prawns, the method including the steps of

introducing post larval prawns into one or more acclimation tanks and feeding the post larval prawns for a period of about 5-9 days, preferably about 7 days to produce pre-juvenile prawns having a size of about 0,04-0,06g, preferably about 0,05g;

transferring the pre-juvenile prawns from the one or more acclimation tanks into one or more raceways provided with circulation means for circulating water in the raceways at a rate of about 3-9cm/sec and feeding the prawns for a period of about 24-31 days, preferably about 28 days to produce juvenile prawns having a size of about 2,0-3,0g, preferably about 2,5g;

transferring the juvenile prawns from the one or more raceways into one or more grow-out tanks and feeding the juvenile prawns for a period of about 10-14 weeks, preferably about 12 weeks to produce harvestable prawns having a size of about 25-35g, preferably about 30g;

at least the acclimation tanks, the raceways and the grow-out tanks being housed in closed structures; and

recycling the water from the grow-out tanks through at least one anaerobic treatment zone and at least one aerobic treatment zone in a water treatment installation.

The water treatment installation served to reduce the levels of nitrate and nitrite in the water.

The acclimation tanks may have volumes of about 1,6m^3. The raceways may have volumes of about 280m^3. The grow-out tanks may have volumes of about 1500m^3. It was found under these conditions that a growth rate of about 2.3g per week during the grow-out phase could typically be obtained.

The method may include circulating the water in the grow-out tanks at a rate based on oxygen need, as aeration and circulation are controlled by a paddlewheel aerator. Preferably, the one or more acclimation tanks, the one or more raceways, the one or more grow-out tanks and the at least one water treatment installation for treating water from the grow-out tanks were all housed in greenhouses.

Numerous growth trials of prawns fed pelleted feed in clear water systems have shown poor growth compared to prawns in green water systems and it was important to add algae and to maintain solids in the water as a source of nutrition. Counts of algae, both introduced and native species, were recorded daily as shown in Table 1. Prawn growth has been shown to be poor if the algal density in the water is less than about 50,000/ml even in the presence of a high settleable solid content (greater than about 3ml/l) and a high suspended solid content (greater than about 100 mg/L). Algal densities were accordingly kept at a high level. This was accomplished by adding algae grown in the algae laboratory and by transferring water from tanks of having higher algal levels to tanks with lower algal levels. Prior art studies have shown that a prawn growth of 0.3g per week can be obtained if prawns are fed algae cultures

alone without any pelleted feed over the course of 8-12 weeks with 70-97% survival. These studies clearly showed the value of algae to the prawn diet. Other prior art studies have shown that more than 50% of all the diet consumed by prawns, even in high density prawn production systems, is composed of environmental nutrition, primarily algae, regardless of the quality or quantity of pelleted prawn feed offered.

The Applicant has found, surprisingly, that if prawns are fed more feed than the amounts disclosed in the present invention decreased growth rates occurred. The Applicant believes that this may be due to the preference prawns have for pelleted feeds. This resulted in at least partial exclusion of the important environmental component of the prawn diet which includes algae both free floating and growing, for example on the paddlewheel and the sides of the raceways, aggregated solids or "biofloc", exoskeletons, faecal strands and detritus. The applicant has also found that overfeeding resulted in increased suspended solids, increased oxygen demand, increased TAN and nitrite in the culture water and an increased dissolved organic nitrogen which may interfere with the consumption of pelleted feed.

The method may thus include the step of feeding the post-larval prawns in the acclimation tanks over a period of 5-9 days, and preferably about 7 days, an amount of feed corresponding to about 17,5-26,3% of the total biomass of the prawns in the acclimation tanks at the beginning of the acclimation period diminishing to about 11,4-17.2% of the total biomass of the prawns at the end of the acclimation period to produce the pre-juvenile prawns.

Preferably the post-larval prawns will be fed an amount of about 20-23% at the beginning of the period and about 12-16% at the end of the period and, more preferably, about 21,9% at the beginning of the period and about 14,3% at the end of the period.

The preferred feeding rates of prawns in the acclimation tanks are set out in Figure 2. The acclimation tanks may be stocked with about 2,0-2,5 kg of post-larval prawns, typically about 2,25g, and will produce about 10-13 kg of pre-juvenile prawns, typically about 11-12kg.

The method may include the step of feeding the pre-juvenile prawns in the one or more raceways, over a period of 26-30 days, and preferably about 28 days an amount of feed corresponding to about 4,9-12,6% of the total biomass of the prawns in the raceways at the beginning of the period, diminishing to about 3,3-6,2% of the total biomass of the prawns at the end of the period, to produce the juvenile prawns.

Preferably the pre-juvenile prawns will be fed an amount of about 8,0-11,5% at the beginning of the period and about 4,0-5,5% at the end of the period and, more preferably, about 10,8% at the beginning of the period and about 5,3% at the end of the period.

The preferred feeding rates of the prawns in the raceways are set out in Table 3. The raceways may be stocked with about 10-13 kg of pre-juvenile prawns, typically about 11,25kg, and will produce about 450-550 kg of juvenile prawns, typically about 500kg.

The method may include the step of feeding the juvenile prawns in the grow-out tanks over a period of 10-14 weeks, and preferably about 12 weeks an amount of feed corresponding to about 2,5-4,6% of the total biomass of the prawns in the grow-out tanks at the beginning of the period diminishing to about 2,1-2,6% of the total biomass of the prawns at the end of the period to produce the harvestable prawns.

Preferably the juvenile prawns will be fed an amount of about 3,0-4,0% at the beginning of the period and about 2,0-2,4% at the end of the period and, more preferably, about 3,6% at the beginning of the period and about 2,37% at the end of the period.

The preferred feeding rates of the prawns in the grow-out tanks are set out in Table 4. The grow-out tanks may be stocked with about 450-550 kg of juvenile prawns, typically about 500kg, to produce about 5000-6000kg, typically about 5475kg, of harvestable prawns.

According to a fourth aspect of the invention, there is provided a method for the intensive production of prawns, the method including the steps of feeding a

prawn population over a period of about 17 weeks, at an initial rate corresponding to about 17,5-26,3% of the total biomass of the prawns, reducing to about 2,1-2,6% of the total biomass of the prawns at the end of the period, to produce harvestable prawns.

The method may include feeding a post-larval prawn population over a first period of about 5-9 days, the post-larval prawns being fed the initial rate of about 17,5-26,3% of the total biomass of the prawns at the beginning of the period diminishing to about 11,4-17.2% at the end of the first period to produce pre-juvenile prawns.

The method may include the step of feeding the pre-juvenile prawns over a second period of 26-31 days, and preferably about 28 days an amount of feed corresponding to about 4,9-12,6% of the total biomass of the prawns at the beginning of the period, diminishing to about 3,3-6,2% of the total biomass of the prawns at the end of the period, to produce juvenile prawns.

The method may include the step of feeding the juvenile prawns over a third period of about 10-14 weeks, preferably about 12 weeks, an amount of feed corresponding to about 2,4-4,6% of the total biomass of the prawns at the beginning of the third period, diminishing to about 2,11-2,58% of the total biomass of the prawns at the end of the third period, to produce harvestable prawns.

The method may include maintaining the water temperature in the acclimation tanks, the raceways, the grow-out tanks and the water treatment installation at about 27-31°C.

The method may include the prior step of purifying seawater in a seawater purification installation and transferring the purified seawater into the acclimation tanks, the raceways and the grow-out tanks. Incoming water may for example be filtered using sand and bag filters and sterilized by UV lights. The treatment of the incoming seawater may be conducted in a separate pump house. Typically, the pump house housed the pumps, filters and tank discharge chamber. In an embodiment of the invention, incoming seawater was pumped from a reservoir using a 250 gallon centrifugal pump, filtered through sand filters and 50 micron bag filters, UV sterilized and then distributed

throughout the culture facility to areas such as the algae and water quality laboratory, acclimation greenhouse, raceways and culture (or grow-out) tanks.

Water in the various culture units may be exchanged at a rate of about 8-12% and preferably about 10% through a separate drain into an open air sedimentation (or settlement) tank with a 24h average retention time, to remove settleable solids, then into a discharge sump equipped with an automatic pump, to discharge clean water back into to the sea.

The method may include introducing algae into the acclimation tanks and/or the raceways and/or the grow-out tanks to produce algal blooms so that the algal count in the water is greater than about 50000/ml and is preferably more than about 200,000/ml. The algae may be selected from species such as *Chaetoceros, T-isochrysis, Tetraselsmis* and mixtures thereof. Naturally, any other suitable algae may be used and many native algae will also grow in raceways and production tanks providing additional nutrition. The highest growth rates have been associated with diatoms in culture water, particularly a native, cyclotella.

According to a fifth aspect of the invention, there is provided a method for the intensive production of prawns, the method including the step of introducing prawns into one or more grow-out tanks each having a centrally positioned outlet and a bottom which slopes inwardly towards the outlet, circulating water in the tank to cause accumulation of waste matter in the vicinity of the outlet and periodically flushing a volume of water through the outlet to cause at least some of the accumulated waste matter to be flushed away.

The water circulation results in centripetal forces which cause accumulation of solids in the centre of the tank.

The intensive production of prawns, which generally refers to production rates of more than 1 kg per cubic meter, in tanks using closed or semi-closed seawater recirculating systems has been found to require intensive aeration and biofiltration to meet the high demands of maintaining adequate water quality. Once the aeration requirements have been met, it has been found that high inorganic waste nitrogen, such

as total ammonia nitrogen (TAN) and nitrite accumulate in the water as feed rates increased to over 30 g/m^3. High levels of TAN (greater than 0,2 ppm of NH_3) and nitrite (greater than 2 ppm) have been found to negatively affect the growth and survival of prawns in tanks. In the aerobic (greater than 4 mg/L dissolved oxygen) environment of production tanks and nursery raceways, TAN was continually absorbed and utilized by algae as well as autotrophic and heterotrophic bacteria, nitrite was not and accumulated to toxic levels and negatively affected growth. However, nitrite is toxic to algae and poorly absorbed by aerobic heterotrophic and autotrophic bacteria and the Applicant has found that prawn production cycles conducted in tanks without a water exchange protocol (raceways) or a mature biofilter media component (acclimation system), accumulated nitrites which resulted in poor prawn growth.

Waste solids, composed of prawn faecal strands, algae, detritus and exoskeletons, accumulated in culture water, created a high oxygen demand and consequently contributed to the deterioration of water quality. The Applicant has found that high concentrations of suspended solids (greater than 300 mg/L) and settleable solids (greater than 3 ml/L) repeatedly resulted in chronic mortality (greater than 50% over the production cycle). Thus a range of waste solids (measured as suspended and settleable solids) was found to be necessary for high survival of the prawns and biofiltration of the water.

Previous production trials in the US and elsewhere have shown that daily water exchange of 100% or more of culture water and the incorporation of large, expensive, external biofilters such as propeller washed bead filters, large tumbling media filters, microscreen filters and others, were necessary to reduce waste nitrogen levels below those which affect prawn growth and survival. However, all of these components were subject to mechanical failure, periodic replacement of parts and maintenance. Due to the intensive capital nature of recirculating aquaculture systems, alternative solutions that were more reliable and less expensive were required. Additionally, aquaculture has in the past come under attack from environmentalists for releasing solid rich effluents, containing waste nitrogen and phosphorous into local coastal areas, resulting in the loss of local flora and fauna through habitat destruction. In addition, it has been found that water exchange becomes impractical when heating

costs associated with growing tropical animals in a temperate environment are taken into account.

In the method of the invention, a more practical approach to maintaining water quality in grow-out tanks to achieve intensive production of prawns was followed. By manipulating flow rates, turbulence, mixing and the size of treatment tank areas, the method of the invention produces different environments to promote the breakdown of various toxic waste compounds. The process of the invention allows the production of prawns at a harvest rate of over 3kg per cubic meter and is able to cope with feed rates in excess of 50g per cubic meter while maintaining excellent water quality with less than 10% daily water exchange.

In a preferred embodiment of the invention, a large dip net may be dragged or scraped along raceway and tank bottoms to ensure that all feed and exoskeletons are consumed, thereby insuring that the prawns receive the complete diet of feed pellets and associated environmental nutrition as described above. In particular an area of low water velocity (about 1cm/sec) was produced in front of the paddlewheel next to the inner wall of the raceways and any wasted feed, exoskeletons and the like was usually found there. Scrapes were accordingly carried out daily in all locations, and any mortalities were recorded. Scrapes were similarly conducted daily in grow-out ponds around the centrally located drain. Feed consumption was in general a good indicator of prawn health and growth.

Feed was stored in an air conditioned or refrigerated container to maintain freshness. Steel transport containers were used and fitted with thermostatically controlled air conditioners to maintain temperatures below 18°C. Insulation material was installed inside the containers to aid cooling and conserve electricity. Feed was generally found to last at least three months in this environment.

The invention is now described, by way of example, with reference to the following Figures, Tables and Examples, in which

Figure 1 shows a schematic block diagram of a prawn production installation in accordance with the invention;

Figure 2 shows a schematic plan view of a raceway in accordance with the invention;

Figure 3 shows a sectional schematic end view of the raceway of Figure 2;

Figure 4 shows the sump of the raceway of Figure 2;

Figures 5 and 6 show top and side views of another embodiment of a sump;

Figures 7 and 8 show plan and side views of a grow-out tank in accordance with the invention;

Figure 9 shows a plan view of a wastewater treatment system;

Figures 10 and 11 show plan and side views of a settlement tank in accordance with the invention;

Figure 12 is a bar graph showing prawn growth and feed rate over time; and

Figure 13 shows the predicted growth of prawns from 0.05g to 30 g as a function of time.

Figures of 14 and 15 show a three-dimensional view and a sectional side view respectively of a central drain assembly.

INSTALLATION FOR THE INTENSIVE PRODUCTION OF PRAWNS

Referring to the drawings, reference 10 generally indicates a prawn production installation in accordance with the invention for the intensive production of prawns. The installation 10 is shown schematically in block diagram format.

The prawn production installation 10 included a seawater purification section 12 which was fed untreated seawater, as shown by the arrow 14, from a seawater reservoir (not shown) and provided purified seawater to an acclimation section 16, a raceway section 18, a grow-out section 20 and an algae culture section 22, as shown by the arrows 24, 26, 28, 30 respectively. The grow-out section 20 was linked to a water treatment section 32 which treated water from the grow-out section 20 and which fed the treated water back to the grow-out section 20 as shown by the double arrows 33.

Algae were fed from the algae culture section 22 to the acclimation section 16 the raceway section 18 and the grow-out section 20, as shown by the arrows 34, 36,

38. The acclimation section 16, the raceway section 18, the grow-out section 20 and the water treatment section 32 were all housed in greenhouses.

The seawater purification section 12 contained a seawater purification installation (not shown) which was provided with sand filters, 50 micron bag filters and UV sterilizers for purifying incoming seawater. The acclimation section 16 contained acclimation tanks (not shown). Each acclimation tank had a volume of about 1,6m^3.

The raceway section 18 contained raceways (also referred to as nursery raceways) 40 as can be seen in Figures 2 and 3. The raceways 40 were in the form of rectangular tanks having longer side walls 42 with lengths of about 30.5m and shorter end walls 44 with lengths of about 8.5m, each having a volume of about 280kg^3. The raceways were housed in greenhouses 52 which were provided with retractable radiation barriers 53. Each raceway 40 was divided by a centrally located, longitudinally extending dividing wall 46 having approximately the same height as the side walls 42 and 44, which extended to about 4.3m from the end walls 44. A motor driven paddlewheel 48 was mounted between one side wall 42 and the dividing wall 46 at one end of the dividing wall 46 and a sump system generally indicated by reference numeral 54 was positioned against the opposite end wall 44 of the raceway 40. The water 62 (see Figures 3 and 4) in the raceway 40 was about 1,2m deep.

The speed of rotation of the paddlewheel 48 was adjustable to cause a flow rate of the water around the dividing wall 46, as depicted by the arrow 50, of between about 3 cm/sec and 9 cm/sec. This rate of flow prevented suspended solids from settling out in the raceway 40.

Referring now to Figure 4, the sump system 54 was in the form of a second tank 56, which was provided with a standpipe 58 extending to a drain pipe 60. A three board weir 64 divided the end wall 44. The weir 64 consisted of three boards 66, 68, 70 which were 5cm thick and spaced about 10cm apart. In use, water 62 in the raceway 40 flowed over the weir 64 into the tank 56 and via the standpipe 58 to the drain pipe 60. The water first flowed through a 4mm screen to prevent escape of prawns (not shown) and then through a 5cm gap located at the bottom of the first group of weir boards 66. Water then flowed over a 5cm gap at the top of the second group of weir

boards, and finally, over the top of a third group of weir boards 70 where the level of water was controlled.

Referring now to Figures 7 and 8, the grow-out section 20 contained grow-out tanks 72 as shown in Figures 7 and 8. Each grow-out tank 72 was roughly square in shape with opposed sides 74, 76 each having a length of about 35m and each held about 1500m^3 of water. The tanks 72 were housed in greenhouses (not shown) which were provided with retractable radiation barriers (not shown). The bottom 78 (see Figure 8) of each tank 72 sloped downwardly at a slope of about 12:1 to a central drain assembly 80 and the sides 82 sloped upwardly at an angle of about 45° over a distance of about 1,4m as can be seen in Figure 8. The drain assembly 80 comprised a pre-cast concrete drain box 81 which was provided with an outlet 82 covered by a screen (not shown), connected to an outlet pipe 84 which extended to a standpipe 86 in a drain box 88 for water to flow to the wastewater treatment system as described below. The water 89 in the tank 72 was about 1,5m deep on average.

Referring to Figures 14 and 15, reference 190 generally indicates another embodiment of a central drain assembly of the type shown in Figure 8. The drain assembly 190 includes a pre-cast concrete drain box 81 and an outlet pipe 84 similar to that of the embodiment shown in Figure 8. The assembly 190 includes a 315 mm UPVC (unplasticised polyvinyl chloride) pipe bend 192 which is cast into the block 81. The block 81 has dimensions of 936 x 936 x 300 millimetres. The pipe bend 192 has a wider open ends 194,196 which form socket formations. The assembly 190 further includes a vertical 300 mm UPVC pipe, or stub stack, 198 which is inserted into the wider open end 194 of the pipe bend 192 spigot-socket fashion. A silicone seal 200 is provided in a 10 x 16mm groove 202 in the block 81 surrounding the stub stack 198. The upper end of the stub stack 198 is sealed with a 4 mm UPVC solid lid 199 which is welded in position. The stub stack 198 is further provided with four horizontal rows of 15 x 185 mm drain slots 204, spaced 12mm vertically apart, with the top and bottom of the slots convex and polished.

The outlet pipe 84 is a 300 mm UPVC pipe which is received in the lower open end 196 of the pipe bend 192 spigot-socket fashion. A circumferentially extending 10mm epoxy coated steel rod 206 is cast into the block 81 and a high density

polyethylene plastic flap 208 is embedded in the concrete of the block 81 and attached to the 10 mm steel rod 206 and extends from the block 81 as can be seen in the drawing.

Each grow-out tank 72 was equipped with four 2-horse power paddlewheel aerators 90 located symmetrically in the corners of the tank 72 about 5,5m from the sides 74, 76 can be seen in Figure 7, and two 1 horse power vertical pump aerators (not shown) centrally located, to circulate and aerate water. The tanks 72 were further provided with twelve heaters 92 extending in two lines across the tank 72. The tank 72 also included a drain box 88 with a wooden sluice gate 96 positioned on the side 76. A pipe 102 extended from one of the sides 74 of the tank 72, where treated seawater from the waste water treatment installation 110 flowed under gravity, from the water treatment installation 32, into the tank 72.

Another pipe 140 extended from the drain box 88 of the tank 72 for draining water from the tank 72 which was then pumped via a 450 gallon per minute pump 113 (Figure 9) into the water treatment installation 32. A second 450 gallon per minute pump was kept on standby in case of failure of the pump 113.

The paddlewheel aerators 90 circulated the water in the tank 72 in a circular direction at a variable rate of velocity diminishing towards the centre of the tank 72. The vertical aerators lifted water up from the bottom and dispersed it on the surface to provide vertical mixing that prevented stratification of the water. The configuration of the tanks 72 provided homogenous mixing of the water to suspend the algae bacteria and aggregated floc which comprised the suspended bio-filtration component of the system.

As the tank ecosystem matured, the prawns and the suspended media generated solids consisting of waste feed, prawn faecal material, and expended bacterial cell walls. This combined sludge product migrated to the center of the tank 72 where it was periodically flushed out of the tank 72. Water was continuously pumped out of the drain assembly 80. The standpipe 86 in the drain box 88 controlled the water level in the drain box 88. A temporary standpipe (not shown) was placed in the drain hole 87 lowering the water level in the drain box 88 below the water level 91 in the tank

72, creating a substantial head of water or difference in water levels. When the temporary standpipe was removed from the drain box 88, the head difference between the tank 72 and the drainage box 88 levels flushed two to three cubic meters of water out of the tank 72 in less than a minute. When the two levels equalized the standpipe was replaced and the process was repeated two to four times per day.

The flushing action created a high water velocity above and around the central drain screen of the tank 72 that swept the accumulated solids away. The sloped tank floor 78 and the centrifugal circulation pattern in the tank caused the accumulation of solids in the tank center. The tank configuration resulted in the concentration and removal of these solids for treatment outside the culture system.

The drain assembly 190 of the embodiment shown in Figures 14 and 15 functions similarly to the drain assembly 80 of the embodiment shown in Figures 7 and 8 and also serves to concentrate solids in the centre of the grow-out tank 72 from where they can be flushed into the waste water treatment system. The drain assembly 190 lacks the screen of the assembly 80 which, in the assembly 190, is replaced with the stub head 198. The stub head 198 is simple to insert and remove from the drain assembly 190 and does not carry the risk of corrosion because of its polymeric construction. The stub head 198 is also cost-effective in that manufacturing and maintenance costs are low and no screens are required. The continual removal of solids prevents anaerobic degradation occurring between flashing cycles.

The water treatment section (see Figure 9) contained a water treatment installation in the form of a rectangular treatment tank 110 which had longer sides 112, 114 which were approximately 28m long and shorter sides 116,118 which were approximately 9m long. The tank 110 was housed in a greenhouse 120 which was provided with retractable radiation barriers (not shown).

A centrally located wall 122 extended from the side 116 to a position about 4m from the opposite side 118. A first saw tooth weir 124 extended between the walls 114, 122 about 4m from the wall 116 to form a surge chamber 126. A second saw tooth weir 128 extended between the end of the wall 122 and the wall 114 to form a facultative chamber 130, and a third saw tooth weir 132 extended between the wall 122

and the wall 112 about 14m from the end wall 118 to form an anaerobic mixing chamber 134 and a clarifier chamber 136. The anaerobic mixing chamber 134 was provided with four floating surface vertical mixers 138. A fourth saw toothed weir 137 lead to a second surge chamber 139 which contained 2 vertical pump aerators 111, 117. The outlet line, or pipe, 140 extending from the drain box 88 of the grow-out tank 72 fed water from the grow-out tank 72 to the treatment tank 110 and the inlet line 102 (see Figures 7 and 9) fed treated water under gravity from the second surge chamber 139 back to the grow-out tank 72. A recirculation line 141 pumped water using 2, 110-gallon per minute pumps 119, 120 from the end of the anaerobic mixing chamber 134 to the surge chamber 126 in order to maintain adequate bacteria, solids and low dissolved oxygen condition in the water treatment section.

Referring now to Figures 10 and 11, reference 150 generally refers to a settlement tank in accordance with the invention. The settlement tank 150 is generally rectangular in shape having longer side walls 152, which are about 11m long, and shorter end walls 154, 156 which are about 5m long and a base 153. The settlement tank was located adjacent the grow-out tank 72, without any greenhouse covering.

A central wall 158 extends between the end walls 154, 156 and divides the tank 150 into two equally sized settlement chambers 160. Two saw tooth weirs 162 extend between the walls 152 and the dividing wall 158 about 2m from the end wall 156 to form two surge chambers 164 and a second pair of saw tooth weirs 166 extends between the walls 152 and the dividing wall 158 about 2m from the end wall 154 to form two discharge surge chambers 168. Water from the raceways 40 or the grow-out tanks 72 is fed via an inlet pipe 170 which divides into two inlet pipes 172 and feeds water into the surge chambers 164. The water then flows over the weirs 162 into the settlement chambers 160 and then over the second set of weirs 166 into the discharge surge chambers 168 and exits the surge chambers 168 via outlet pipes 170 connected to a pipe 172 from where it is fed to a sump (not shown). The depth of the water 160 in the tank 150 was about 3m.

EXAMPLE

Acclimation

The acclimation greenhouse was divided into two sections. The acclimation area contained twenty two 1.6m^3 acclimation tanks (not shown) which could acclimate about 500,000 prawns for stocking into the raceways (also referred to as nursery raceways). Each tank contained one disc diffuser, a 2000 watt heater controlled via a thermostat and a simple to operate, external microcomputer. Drains were centrally located in the tanks and covered with 750 micron mesh to prevent prawns from escaping. The tanks were covered with 20% shade cloth to prevent the prawns from jumping out and to provide decreased lighting to aid both prawn and algal growth.

Each side of the acclimation greenhouse was fitted with a 2 horse power centrifugal pump (with one on standby) rated at more than 100 gallons per minute for the recirculation of water. The pump provided a recirculation rate for each acclimation tank of 4.5 gallons per minute and a maximum turnover rate of 7.5 times per day. If fewer tanks were used, flow rates could be varied depending on need. The pumps were operated continuously to allow for the proliferation of autotrophic bacteria in the biofilter. Diffused air for the acclimation greenhouse was provided by two 3 horse power regenerative blower motors which provided 160 cubic feet per minute of compressed air. The amount of air delivered to the tanks was calculated to be in excess of that needed to produce the required number of healthy post-larvae to stock into a nursery raceway (minimum of 58 cubic feet per minute for each side). A dual drain system was incorporated in the tanks so that water could be either directed to recirculation components or discharged to the sedimentation tank 150.

The acclimation tanks were chilled and arriving bags of post-larval prawns were removed from their boxes and the plastic bags containing the post-larval prawns were placed in the chilled acclimation tanks, after which the water temperature was raised to 30°C over 24hrs. The acclimation cycle lasted 7 days after which prawns were gathered and the survival of prawns estimated. The prawns were then transferred in 20 litre plastic buckets. The water level in the acclimation tanks was then lowered to about

20cm and the post-larval prawns were placed in a floating counting bucket, which maintained a constant known volume while floating in the water. This was accomplished by placing a 750 micron screen over a precisely located hole in the counting bucket. Density measurements were made by stirring the high concentration of post-larval prawns and taking the average density of 50ml samples with glass beakers, counting all post larval prawns in the sample and extrapolating to determine the total amount.

During start of the 7 day acclimation cycle, the temperature and salinity of the acclimation tank water was regulated to be the same as that of the water in the bags of incoming post-larval prawns (typically 30 ppt and 16-18°C) and slowly increased using heaters. During the acclimation period, the post-larval prawns were fed at the rate listed in the feed tables in Table 2. Additional nutrition for the postlarval prawns was provided by artemia and algal/detrital aggregates.

The parameters which had to be controlled when receiving and acclimating post larval prawns were temperature, salinity, oxygen, and pH. Packing water was usually chilled to between 16°C and 18°C, and arrived between 16°C and 23°C. When acclimating for temperature, the rise of temperature was maintained at about 1°C every 10 minutes. The water used usually had a salinity of about 30ppt to 31ppt. Increases or decreases in salinity were limited to 1ppt every 10 minutes. Control of the pH of the water during acclimation was important especially if the travel time of the post-larval prawns was more than about 24 hours. At packing of the post-larval prawns, the pH was about 8.3, but after 48 or more hours in the bag, the pH usually dropped to around 6.5 and it was important not to allow a pH increase to exceed by more than 0.1 every 10 minutes.

The low pH was due to carbon dioxide accumulation in the water because the animals were sealed in a plastic bag and the CO_2 could not escape. This effect was minimized by having a large enough void (gas space filled with pure oxygen) above the water. Low pH values could also be caused by elevated water temperatures during transport resulting in a higher metabolic rate in the animals to respire higher amounts of CO_2. If DO was lower than about 3.0ppm, a fine pore diffuser with pure oxygen was used to slowly bubble oxygen into the water without altering the pH.

The acclimation greenhouse also contained seven 17m^3 tanks (not shown) which were used as additional acclimation units, nursery, algal, rotifer or artemia production tanks and units for research on biofloc development, carbon manipulation and feed trials. All nursery tanks were equipped with the same pumping, filtration and UV equipment as described above for the acclimation tanks.

The acclimation greenhouse was provided with sand filters, bag filters and UV sterilizers (not shown) for treating incoming water a second time, before stocking of algae. Post-larval prawns were very sensitive to poor water quality and 1m^3 biofilters were used to maintain the proper environmental conditions in the acclimation tanks. A separate 0.5 horse power air blower was installed to aerate the biofilter, to ensure proper environmental conditions for the maximum proliferation of waste eating bacteria.

Biofilters containing 1m^3 of biofilter media removed total ammonia nitrogen and nitrite after a period of constant operation of about 6 weeks, after which time a maximum feed rate of 3kg of "type 0" feed (www.rangen.com) was used to feed the post-larval prawns. Acclimation water was maintained at an average daily temperature of 30°C with morning temperatures of about 29°C and late afternoon temperatures reaching about 31°C.

Bypass options were installed to allow the biofilter and sump to be used separately from the mechanical filters, to maintain concentrations of algae, detrital aggregates, and zooplankton at proper densities during normal operation. Sand and bag filters removed particles larger than 30µ, while UV sterilizers maintained biosecure conditions while breaking down organic matter. Normally before a production cycle began, the water was filtered and sterilized between cycles directly before stocking algae into the acclimation system, anticipating the arrival of post larval prawns by a few days.

Algal culture

Algal blooms were established in the acclimation tanks using preferred nutritious algal species cultured in the algae culture section 22. A combination of *T*-

Isochrysis, Tetraselmis and Chaetoceros was shown to produce excellent post-larval growth. Algal blooms were established in the acclimation tanks at a density of about 50,000/ml for *Chaetoceros* and *T-Isochrysis* and 10,000/ml of *Tetraselsmis*, for a total combined density of about 100,000-200,000 cells/ml. Suitable replacement of these algal species could be incorporated depending on availability. Algal cultures were obtained from local algae growers or from international algae labs such as CSIRO in Tasmania. Brine shrimp were hatched in brine shrimp hatchers and maintained in the acclimation water at a rate of 100-200 artemia per post-larval prawn per day.

The algae culture section 22 consisted of a separate building (not shown) of two rooms, and algae were cultured in a procedure known as a "modified batch culture". This procedure is described on pages 51-52 of Hoff and Snells Plankton Culture Manual (1987). In an embodiment of the invention, the primary culture room contained 500ml and 1ℓ Erlemeyer flasks and 20ℓ carboys as algae culture units. The primary culture room also contained a microwave, dishwasher for cleaning glassware and a wall mounted filtration and UV sterilizer unit. Sterilization of media for 500ml and 1ℓ flasks was accomplished by using a microwave oven, while full strength sea water was first sterilized using a wall mounted filtration unit before filling the carboys. An enclosed laminar flow hood was installed for sterilizing the outer rim of culture flasks using a Bunsen burner before transferring the algae to the carboys. Lighting was provided by a combination of standard fluorescent and actinic bulbs to provide the necessary red and blue parts of the light spectrum needed for algal growth.

Diffused air was provided by a 0.5 horse power blower motor located externally, injected with CO_2 before being used to circulate and aerate algae cultures in carboys and cylinders. Diffused air could be a source of contamination and accordingly was not incorporated into "purer" cultures in flasks. Occasionally, ciliates or protozoans occurred in carboys and cylinders during routine algal counts but these were found not to be detrimental to algae production. Diffused air was filtered through a 0.5 micron in line filter before being distributed into algae cultures via common plastic aquaria tubing, connected to rigid plastic tubing.

The secondary algae culture room contained 80 litre cylinders for the grow-out of algae before transferring via a portable submersible pump and hose to the

acclimation tanks and nursery raceways. Algae were counted with a compound microscope and hemacytometer (Hoff and Snell, 1987) five days every week to insure proliferation of algal species. Data on various species were entered into a spreadsheet for monitoring and collating (see Table 1).

Besides algae grown in the laboratory and stocked intentionally in raceways and tanks, it was found that native algal species eventually invaded culture water and grew exponentially. Diatoms were previously shown to be the most nutritious of algal species and their growth was encouraged by transfer between adjacent raceways, especially during the beginning of a production cycle. Native species such as *Crytomonas, Amphidinium, Chlorella* and many others, appeared to grow well and provided some nutrition to the prawns. These species also increased to numbers large enough to provide excellent TAN uptake. However it was found that the best growth in raceways took place with diatoms present. The lower level to support adequate growth was found to be about 50,000 cells/ml of combined species, while numbers in the millions/ml were found during peak summer periods.

Nursery raceways

After a seven day acclimation cycle, the pre-juvenile prawns having a mass of about 0.05g were transferred from the acclimation tanks into the nursery raceways 40 for growth to approximately 2.5g over a period of about 4 weeks. About 225,000 prawns were stocked into the nursery raceways 40 yielding about 2 kg/m^3 of juvenile having a mass of about 2.5g for a total mass of about 563 kg. During this time the prawns were fed as set out in Table 3. Generally four of the 1.6m^3 tanks were harvested at a time and the prawns were transferred in buckets to the raceways 40 at 30°C (+/- 0.5 °C). Algae were stocked from 80 litre algae cylinders into the raceways 40 at about 1000/ml of each species and, within about a week, the algae acclimated to the raceway conditions and began exponential growth.

Netting of 1m in height (not shown) was installed around the nursery raceways 40 to prevent prawns from jumping out. Simple easy release clips were used to remove nets for prawn sampling, harvesting cleaning and feeding. The water in each raceway 40 was circulated by the paddlewheel 48. The water speed was regulated by

adjusting the rotational speed of the paddlewheel 48 on a digital readout (where 1 rpm was equal to a water flow rate of 6.2cm/sec). Generally, water was circulated at 0.5 rpm for the first week, increasing to 1 rpm during the fourth week. Increased water velocities (above about 6,2cm/sec) were found to result in poor growth, while water velocities of about 6 cm/sec resulted in a good suspension of solids. This resulted in good biofiltration and additionally provided an extremely important source of nutrition for prawn growth. If suspended solids were allowed to settle out, poor water quality resulted because of the creation of anaerobic toxic substances such as hydrogen sulphide, methane, carbon dioxide, TAN and nitrite. In addition, because juvenile and sub-adult prawns are benthic animals they avoided anaerobic sediments that accumulated in raceways. The negative effects of anaerobic areas in culture tanks and raceways have been well documented. The circulation of the suspended solids consequently is an important feature of the invention.

Aeration of the raceways 40 was provided by two 3 horse power regenerative blowers (not shown) which produced 320 cubic feet per minute of air for the disc diffusers in each raceway. This was in excess of the 247 cubic feet per minute calculated to be necessary for prawn production at the maximum oxygen need, based on the maximum daily feed rate in each raceway 40 of about 19 kg at the harvest prawn biomass of 2 kg/m^3.

All nursery raceways 40 were equipped with two 1-horse power vertical pump aerators which were placed in the raceways 40 as contingency for low DO. Water in the raceways 40 was exchanged via the three board weir system 64. A 3 mm screen was installed at the inner opening of each raceway 40 near the sump system 54, to prevent the escape of prawns. The first group of weir boards 66 contained a bottom opening where water from the raceway bottom entered flowing up and over a second group of weir boards 68 which had an opening at the top and the third outer group of boards, innermost to the raceway sump controlled the level of water in the raceway.

The water quality in the raceways was maintained by strict water exchange. It has been shown that toxic waste nitrogen, in the form of nitrite, accumulates in raceways and that this results in poor and variable prawn growth. Nitrite accumulation has also been found to respond very poorly to water exchange. If low

levels of nitrite were allowed to accumulate in raceway water, a large water exchange (greater than 50% per day) would have to be incorporated to dilute the nitrite concentration. This would result in the loss of nutritious algal species from the culture water and, in turn, poor and variable growth of prawns.

Approximately 70% of the nitrogen ingested by prawns in the form of pelleted feed is expelled through the gills of the prawns, after digestion, as a waste product known as total ammonia nitrogen (TAN). Once this total ammonia nitrogen has been expelled into the culture water, it is utilized by algae as a source of nitrogen for algal growth. The prawns in turn then feed on the algae. The algae thus function as an important source of nutrition as well as a very necessary waste absorbing, biofiltration component. Nitrite only forms from total ammonia nitrogen as part of the well known nitrification process which is entirely aerobic. If total ammonia nitrogen is allowed to accumulate in the culture water, the formation of nitrite by aerobic, oxidizing bacteria generally follows within days. The management and control of TAN was therefore necessary to control the accumulation of nitrite. Since algae effectively consume TAN, the accumulation of TAN was used as an indication that algae growth in the culture water was slowing down. At that stage 10-20% of the culture was exchanged per day until the TAN concentration in the culture water had been reduced to less than 0.5 mg/ℓ. A dual benefit of water exchange was the fact that, as TAN was diluted in the culture water, algal densities were reduced, thereby creating more “room” for algae to grow, absorbing more TAN in the process, and so on. This process resulted in low levels of nitrite, maximum amounts of nutritious algae in the culture water and prawn growth that was over twice the industry standard.

Prawn growth was determined at the end of the acclimation cycle and weekly in the nursery raceways 40 and grow-out tanks (see below). A sample of at least 50 prawns was taken from 3 different areas of the raceways 40 for growth determination. Prawn samples were weighed using portable scales and counted for average weight determination. The prawns were captured using large dip nets for the acclimation cycle and the first and second weeks of nursery growth in the raceways, thereafter cast nets of various sizes were used. Variability was compared between samples within raceways and tanks to determine the number of samples needed for an accurate average of individual prawn weight in each tank.

Transferring the prawns from the raceways 40 was achieved by lowering the raceway water level to about 20cm, seining and gathering the prawns, transferring the prawns to pre-weighed 20ℓ plastic buckets (containing oxygen rich seawater from cylinders and diffusers) placed on a portable scale to determine prawn weight and then immediately transferred into a 200ℓ transfer tank mounted on the trailer of an ATV. A pure oxygen cylinder equipped with air line and diffuser was mounted next to the transfer tank to provide adequate oxygen during transit to the grow-out tanks 72.

Grow-out of prawns

Each 1500m^3 grow-out tank 72 was stocked with 200,000 prawns. The prawns grew at a rate of 2.5g per week on average for a 12 week growing period with a 75% survival rate before harvest. During the grow-out period the prawns were fed as set out in Table 4. A total of about 5 metric tons of prawns having a mass of about 30g was harvested. YSI monitoring and water quality determination was conducted. Wastewater treatment was necessary to grow prawns in the grow-out tanks.

Water Treatment

Water from the grow-out (or culture) tanks 72 was recirculated through the wastewater treatment section 32 with a turnover rate of 2 x per day. The separate chambers in the tanks 110 created different environments for the high density proliferation of various bacteria, which consumed waste nitrogen in various inorganic and organic forms. The members of this biological community interacted and complemented each other, creating a complex and stable ecosystem. Each chamber contributed differently in terms of waste nitrogen reduction.

Water flowed through the wastewater treatment section 32 continually (24h per day at a rate of about 450 gallons per minute). The water was first pumped from the grow-out tanks 72 through the bottom drain assembly 80 and into a sump 88 which periodically manipulated flow rates to create increased surge velocities, facilitating the collection of nitrogen and phosphorous rich, waste solids and transferring them to the wastewater treatment area, as described above. Discharged water,

containing solids was directed into the bottom of the surge chamber 126 which reduced turbulence. Water then flowed over the weir 124 into the facultative chamber 130 which was a quiescent zone. The facultative chamber 130 collected waste solids through sedimentation. The depth and length of the facultative chamber 130 allowed the solid waste particles to sink to the bottom from the surface layer to a lower level dominated by anaerobic bacteria that actively digested the particles. The upper layer was an anoxic layer which prevented the production of odours as it passed over the sediments collected on the bottom. Nitrates, sulphur and organic carbon were converted to nitrogen, hydrogen sulphide, carbon dioxide and methane gas which diffused out of the culture water into the atmosphere. These bubbles of waste gas were clearly seen throughout the cycle. Phosphorous and nitrogen compounds were also collected and stored in the sediments for later digestion in the anaerobic mixing chamber.

Water exited the facultative chamber 130 over the weir 128 into the anaerobic mixing chamber 134 with dissolved oxygen concentrations of less than 0.5ppm. Here anaerobic bacteria reduced nitrite through denitrification into nitrogen gas which was expelled into the atmosphere (78% nitrogen gas). During experimentation early on, this process reduced the nitrite concentrations in the culture water from an initial value of about 40mg/ℓ to 0mg/ℓ in less than 48 hours.

Finally water entered a second sediment (or clarifying) chamber 136 via the weir 132. This chamber was a quiescent, anoxic sediment chamber which primarily collected bacterial cell walls produced in the mixed anaerobic portion. Once again bacterial communities in this area were different in terms of their preference to consume waste nitrogen. Water then passed over the fourth weir 137 into the final surge chamber 139 before being discharged via gravity back to the culture tank.

The wastewater treatment section 32 also circulated water via two submersible pumps 119, 120 at a total rate of 200 gallons per minute through the feed line 141 from the end of the anaerobic mixture chamber 134 back to the first surge chamber 126. This recirculation process allowed a “second pass” of wastewater through the anaerobic settling chamber 130 and mixing anaerobic chamber 134 to further treat water before being directed back to the grow-out tanks 72. This also

maintains a certain amount of anaerobic bacteria, low DO and solids in the water treatment installation necessary for denitrification.

The water purification system of the present invention was simple, as it involved water flowing through concrete chambers, with the incorporation of mixers in one section, aerators in another and a simple recirculation system. It was a low maintenance, multi-environment water treatment facility that used a complex of indigenous bacterial associated communities which thrived on waste nitrogen. The incorporation of 10% water exchange, if necessary, could be made in the final surge chamber 139 located after the aerobic settlement chamber 136. However, the production tank 72 was run on a 10% waste water protocol. The treated water was of good quality with low levels of solids and waste nitrogen.

Water Quality Determination

A YSI wall mounted panel was located inside each greenhouse for 24 hr measurement and recording of DO, pH and temperature. All YSI wall mounted units were linked via wireless communication to a PC for continual observation. Aquaculture management software created by Sondolo (Bosasa) and was a necessary and integral part of the invention was used to collate and archive data as well as to provide an alarm via cell phone in the event that water quality parameters fell outside of a desired range.

The levels of DO, temperature and pH were also measured every two hours by greenhouse workers. Total ammonia nitrogen and nitrite were measured daily using practical water quality kits (HACH or similar). Other water quality parameters such as alkalinity, suspended and settleable solids and nitrate were measured twice weekly.

Water quality parameters were kept in the ranges listed in Table 6. Unionized ammonia is the toxic fraction of TAN and was calculated using a well known equation embedded in the spreadsheet of Table 7. The percent of un-ionized ammonia increased with increasing temperature and pH. TAN was reduced in culture water through uptake by algae and bacteria and water exchange. During a culture cycle, TAN was the first waste nitrogen compound to appear. Reduction in TAN responded well to

10% water exchange often decreasing far more than 10%. After a few weeks of TAN reaching values as high as 5ppm or more in some cases, nitrite registered during daily water quality checks. Because nitrite did not respond well to water exchange it was monitored daily and compared against expected growth rates to check for any negative effects. Side by side comparisons showed prawns of sizes less than 20g grew nearly equally as well in water of 4ppm nitrite nitrogen compared with culture water of 0ppm, at the same feed rate and environmental conditions. However, the preferred conditions are listed in Table 6.

Feeding

Feed types relating to prawn size are set out in Table 5 and the ratio of feed to growth is set out in Figure 12. Prawns in the acclimation tanks, nursery raceways and grow-out tanks were usually fed four times per day by evenly adding the feed to the tanks and raceways. The prawns were fed a diminishing amount feed as the overall biomass increased. The quantities of feed fed to the prawns in the acclimation tanks, the raceways 40 and the grow-out tanks 72 as a function of the total biomass of the prawns in the acclimation tanks, the raceways 40 and the grow-out tanks 72 are set out in Tables 2, 3 and 4. The predicted mass of the prawns is set out in Figure 13.

Feeding trials

A production trial conducted in 17m^3 tanks showed, surprisingly, that increased feeding of prawns, above the preferred levels set out in Tables 2, 3 and 4 resulted in decreased growth. Prawns stocked in three 17m^3 tanks at a rate of 1000 per tank, with an average mass of about 0,44g, were offered three different amounts of prawn feed (35% protein, Rangen). Prawns in the first tank were fed daily at 50% of the preferred feed rate set out in Tables 2, 3 and 4, prawns in the second tank were fed at 100% of the preferred feed rate and prawns in the third tank were fed at 150% of the preferred feed rate according to a bioenergetic model (Schuur, 1992[1)]). The feed was divided into 4 equal parts and the prawns were fed every six hours. Although all feed was consumed in all tanks, and checked by daily scrapes of tank bottoms, the additional feed consumption did not result in increased growth. In fact, the prawns in the third tank, which received the additional feed, actually grew less for 4 consecutive weeks during the production trial (Figure 13). This was probably due to the preference prawns

have for pelleted feed, as excess feed consumption would result in reduced foraging for environmental nutrition which resulted, as described above, in increased prawn growth. All tanks were on a single recirculating system, with a 3 x per day turnover of water. Temperatures were maintained at 27°C on average as larger prawns were also housed in similar tanks on the same recirculation system. All water quality parameters were maintained as described above in the preferred range for optimum prawn growth by recirculating culture water through a $1m^3$ biofilter.

A second trial was conducted with larger prawns stocked into a single $17m^3$ tank. Prawns having an average mass of about 43g were stocked into a single tank at a stocking level of about 15 prawns per cubic meter or 251 animals in total. For two weeks, the prawns were feed at 0% of the preferred feed rate. This was estimated to be enough to maintain the metabolism of the prawns but not to provide energy for growth according to a bioenergetic model (Schuur, 1992[1)]) (0 on graph set out in Figure 12 below). For the next consecutive weeks, the prawns were fed at the preferred feed rate, indicated as 1 in Figure 12. For the first two weeks, the prawns grew at an average rate of about 0.8g per week, indicating that they probably consumed environmental nutrition for growth. For the following two weeks, when fed at the preferred feed rate, the prawns grew at an average of about 3.25g per week. The average daily water temperature was 27°C.

A third feed trial, similar to the second, was conducted during the same period in an adjacent tank using 274 animals with an average weight of about 54g. In this trial the prawns were fed at 3.5 times the preferred feed rate (350%) for the first two weeks, while in the third and fourth week the prawns were fed at 100% of the preferred feed rate. The prawn growth rate averaged about 1.9g per week during the first two weeks while the growth for the third and fourth weeks averaged about 2.7g per week.

Table 1

Typical algae and protozoa data collected for display, collation and average determination

Algae count/ml														
Day		Chlorella	C.m	Cyclotella	T.c	T-Iso	other	Nanoplankton	Navicula	Diatoma	Euglena	Nitzchia	Amphidinium	euplotes
1	R 1	5000	5000	15000	0	25000	25000	1,500,000	5000	10000	15000	5000	0	0
1	R 2	10000	0	5000	0	0	10000	1,375,000	5000	5000	20000	0	10000	0
1	R 3	0	5000	0	0	15000	25000	1,500,000	0	0	0	0	10000	0
1	A	0	0	0	0	0	40000	1,500,000	0	0	0	0	0	0
1	N	15000	0	15000	0	0	115000	500,000	5000	0	0	5000	0	0
1	G	0	5000	0	5000	15000	10000	3,875,000	0	0	0	0	70000	0
1	Wwt	5000	0	5000	0	20000	15000	3,625,000	0	0	0	0	25000	0
2	R 1	0	0	0	10000	5000	5000	2,000,000	0	0	15000	5000	5000	0
2	R 2	10000	0	20000	10000	0	20000	1,375,000	5000	0	0	0	5000	0
2	R 3	0	0	0	0	15000	60000	875,000	0	0	0	0	20000	0
2	A	0	0	0	0	0	30000	-	0	0	0	0	0	0
2	N	5000	0	15000	0	0	130000	375,000	0	0	0	5000	5000	0
2	G	5000	0	0	0	0	55000	3,000,000	0	0	0	0	40000	0
2	Wwt	0	0	0	0	5000	25000	2,000,000	0	0	5000	0	45000	0

R = raceway, A = acclimation tank, N = Nursery tank, G = Grow-out tank, Wwt = Waste Water Treatment

Table 2

Expected weights of individual prawns, number and % survival and kg of feed required for 7 day acclimation cycle of post-larvae.

Time Days	Weight grams	# surv /day	% survival /day	Preferred kg feed req/d	Preferred feed %/day	Low Range feed %/day	High Range feed %/day
1	0.009	250,000	100.00%	0.49	21.90%	17.52%	26.28%
2	0.016	242,611	97.00%	0.75	18.90%	15.12%	22.68%
3	0.021	238,999	95.60%	0.9	17.70%	14.16%	21.24%
4	0.027	235,441	94.20%	1.07	16.70%	13.36%	20.04%
5	0.034	231,936	92.80%	1.26	15.80%	12.64%	18.96%
6	0.042	228,483	91.40%	1.45	15.00%	12.00%	18.00%
7	0.052	225,081	90.00%	1.67	14.30%	11.44%	17.16%

Table 3

Expected weights of individual prawn, number and % survival and kg of feed required for a 4 week nursery cycle of juveniles.

Time wk	Weight grams	# surv /wk	% survival /week	kg feed req/wk	Preferred feed %/day	Low Range feed %/day	High Range feed %/day
0	0.05	225081	100%				
1	0.25	218648	97%	23.3	10.78%	4.99%	12.62%
2	0.75	212398	94%	50.2	7.49%	4.09%	9.71%
3	1.75	206327	92%	117.9	6.70%	3.63%	7.48%
4	2.5	200429	90%	147.8	5.27%	3.30%	6.21%

Table 4

Expected weights of individual prawn, number and % survival and kg of feed required for a 12 week production cycle of market prawns (30 g).

Time Wk	Weight grams	# surv /wk	% survival /week	Preferred kg feed req/wk	Preferred feed %/day	Low Range feed %/day	High Range feed %/day
0	2.5						
1	4.0	200,000	100%	203	3.62%	2.48%	4.60%
2	5.8	196,432	98%	276	3.49%	2.44%	4.17%
3	7.8	194,672	97%	345	3.27%	2.39%	3.86%
4	10.0	192,928	96%	407	3.01%	2.33%	3.62%
5	12.5	191,199	96%	490	2.93%	2.28%	3.41%
6	15.0	189,486	95%	555	2.79%	2.26%	3.22%
7	17.5	187,789	94%	620	2.69%	2.23%	3.05%
8	20.3	186,106	93%	691	2.62%	2.19%	2.96%
9	23.0	184,439	92%	753	2.54%	2.16%	2.85%
10	25.5	182,786	91%	806	2.47%	2.15%	2.72%
11	28.0	181,149	91%	856	2.41%	2.13%	2.63%
12	30.5	179,526	90%	909	2.37%	2.11%	2.58%

Table 5

Feed types and schedules for prawn production

Feed type	Feed size mm	% protein	% Fat	Prawn Size g
No. 0	<0.6	45	9	0.009 - 0.01
No. 1	0.6 - 1.0	45	9	0.1 - 0.25
No. 2	1.0 - 1.4	45	9	0.25 – 0.5
No. 3	1.4 - 1.7	45	9	0.5 - 1.0
No. 4	1.7 - 2.8	45	9	1.0 - 3.0
3/32"	2.4	35	8	3.0 – 20
3/32"	2.4	40	8.5	20-40
3/32"	2.4	45	9	40-70

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Table 6

Acceptable ranges of water quality parameters in culture tanks.

Variable	Acceptable range	Unit
DO	>4.5	Ppm
Temp	27-30	℃ (dependent on size of prawns)
pH	7.2-8.5	pH units
Unionized ammonia	<0.1	ppm
Nitrite-Nitrogen	< 1	ppm
Nitrate-Nitrogen	<200	ppm
Alkalinity	110-180	ppm
CO2	< 20	ppm
Suspended solids	20-300	mg/L (dried weight)
Settleable solids	0-3	ml/L

Table 7

Spreadsheet for displaying water quality, algae and feed consumption information

Day	Location	TAN	Temp	Pka (calc)	pH	Fract (calc)	NH3 (calc)	NO2	NO3	Alkalinity	CO2 (calc)	Sus solids	Settle solids (ml/l)
1	R 1	0.5	26.3	9.207	7.66	0.0150	0.007	2.7	24	116	5.1	84.27	2.0
1	R 2	0.1	27.3	9.176	7.54	0.0122	0.001	2.1	20	112	6.4	59.93	1.75
1	R 3	1	26.75	9.193	7.34	0.0075	0.007	2.3	24	136	12.4	86.6	1.75
1	A	0.1	26.12	9.212	7.94	0.0279	0.003	0.0	8	152	3.5	18.93	0.00
1	N	0.5	25.35	9.236	7.66	0.0140	0.007	0.6	6	152	6.6	39.93	0.00
1	G	2	26.2	9.210	7.33	0.0070	0.014	2.9	70	124	11.6	61.93	0.00
1	Wwt	2	25.6	9.228	7.52	0.0104	0.021	3.0	80	124	7.5		
2	R 1	0.75	26.52	9.200	7.42	0.0088	0.007	1.4	24	116	8.8		
2	R 2	0.1	27.3	9.176	7.56	0.0128	0.001	1.7	20	112	6.2		
2	R 3	1	27.03	9.184	7.29	0.0068	0.007	2.7	24	136	13.9		
2	A	0.1	26.16	9.211	7.94	0.0279	0.003	0.0	8	152	3.5		
2	N	0.5	25.5	9.231	7.68	0.0148	0.007	0.6	6	152	6.3		
2	G	4	26.2	9.210	7.31	0.0067	0.027	2.0	70	124	12.1		
2	Wwt	4.00	25.39	9.234415	7.76	0.0177	0.071	2.7	80	124	4.3		

R = raceway, A = acclimation tank, N = Nursery tank, G = Grow-out tank, Wwt = (Waste Water Treatment installation)

[1] Schuur 92 : A bioenergetic model for application to intensive fish culture system management; A.M. Schuur, American Fisheries Society Symposium 10:393-401, 1991

CLAIMS:

1. A prawn production installation for the intensive production of prawns, the production installation including

at least one seawater purification installation for the purification of incoming seawater;

one or more acclimation tanks;

one or more raceways provided with circulation means for circulating water in the raceways at a rate of about 3-9 cm/sec;

one or more grow-out tanks; and

at least one water treatment installation for treating water from the grow-out tanks, the or each water treatment installation having at least one anaerobic treatment zone and at least one aerobic treatment zone;

at least the acclimation tanks, the raceways and the grow-out tanks being housed in closed structures.

2. A prawn production installation as claimed in claim 1, in which the rate is about 5-7 cm/sec.

3. A prawn production installation for the intensive production of prawns as claimed in claim 1 or 2, in which the closed structures are greenhouses.

4. A prawn production installation for the intensive production of prawns as claimed in claim 3, in which the greenhouses are provided with retractable radiation barriers for conserving heat.

5. A prawn production installation for the intensive production of prawns as claimed in any one of claims 1 to 4 inclusive, in which the means for circulating water in the raceways is in the form of one or more motor driven paddlewheels.

6. A prawn production installation for the intensive production of prawns as claimed in any one of claims 1 to 5 inclusive, in which the at least one seawater

purification installation, the one or more acclimation tanks, the one or more raceways, the one or more grow-out tanks and the at least one water treatment installation for treating water from the grow-out tanks are housed in greenhouses.

7. A prawn production installation for the intensive production of prawns as claimed in any one of claims 1 to 6 inclusive, in which the acclimation tanks have volumes of about 1,6m^3, the raceways have volumes of about 280m^3 and the grow-out tanks have volumes of about 1500m^3.

8. A prawn production installation for the intensive production of prawns as claimed in any one of claims 1 to 7 inclusive, in which the prawns are selected from *Litopeneaus vannamei, Litopeneaus monodon, Litopeneaus chinensis, and Litopeneaus stylirostris.*

9. A prawn production installation for the intensive production of prawns as claimed in claim 8, in which the prawns are *Litopeneaus vannamei.*

10. A prawn production installation for the intensive production of prawns as claimed in claim in any one of claims 1 to 9 inclusive, which includes an algae culture installation for culturing algae.

11. A prawn production installation for the intensive production of prawns, the production installation including

at least one seawater purification installation for the purification of incoming seawater;

one or more acclimation tanks;

one or more raceways provided with circulation means for circulating water in the raceways;

one or more grow-out tanks;

at least one water treatment installation for treating water from the grow-out tanks,

at least the acclimation tanks, the raceways and the grow-out tanks being housed in closed structures, the or each grow-out tank having circulation means for circulation water in the grow-out tank, a centrally positioned drain opening, a bottom

which slopes inwardly towards the drain opening and a flushing mechanism for perodically flushing a volume of water through the drain opening.

12. A method for the intensive production of prawns, the method including the steps of

introducing post larval prawns into one or more acclimation tanks and feeding the post larval prawns for a period of about 5-9 days, to produce pre-juvenile prawns;

transferring the pre-juvenile prawns from the one or more acclimation tanks into one or more raceways provided with circulation means for circulating water in the raceways at a rate of about 3-9cm/sec and feeding the prawns for a period of about 24-31 days;

transferring the juvenile prawns from the one or more raceways into one or more grow-out tanks and feeding the juvenile prawns for a period of about 10-14 weeks, preferably about 12 weeks to produce harvestable prawns;

at least the acclimation tanks, the raceways and the grow-out tanks being housed in closed structures; and

recycling the water from the grow-out tanks through at least one anaerobic treatment zone and at least one aerobic treatment zone in a water treatment installation.

13. A method as claimed in claim 12, which includes the step of feeding the post-larval prawns in the acclimation tanks over a period of 5-9 days an amount of feed corresponding to about 17,5-26,3% of the total biomass of the prawns in the acclimation tanks at the beginning of the acclimation period diminishing to about 11,4-17.2% of the total biomass of the prawns at the end of the acclimation period to produce the pre-juvenile prawns.

14. A method as claimed in claim 13, in which the post-larval prawns are fed an amount of about 20-23% of the total biomass of the prawns in the acclimation tanks at the beginning of the period and about 12-16% of the total biomass of the prawns in the acclimation tanks at the end of the period.

15. A method as claimed in any one of claims 12 to 14, which includes the step of feeding the pre-juvenile prawns in the one or more raceways, over a period of 26-30 days, an amount of feed corresponding to about 4,9-12,6% of the total biomass of

the prawns in the raceways at the beginning of the period, diminishing to about 3,3-6,2% of the total biomass of the prawns at the end of the period, to produce the juvenile prawns.

16. A method as claimed in claim 15, in which the pre-juvenile prawns are fed an amount of about 8,0-11,5% at the beginning of the period and about 4,0-5,5% at the end of the period.

17. A method as claimed in any one of claims 12 to 16, which includes the step of feeding the juvenile prawns in the grow-out tanks over a period of 10-14 weeks, an amount of feed corresponding to about 2,5-4,6% of the total biomass of the prawns in the grow-out tanks at the beginning of the period diminishing to about 2,1-2,6% of the total biomass of the prawns at the end of the period to produce the harvestable prawns.

18. A method as claimed in claim 17, in which the juvenile prawns are be fed an amount of about 3,0-4,0% at the beginning of the period and about 2,0-2,4% at the end of the period.

19. A method for the intensive production of prawns, the method including the steps of feeding a prawn population over a period of about 17 weeks, at an initial rate corresponding to about 17,5-26,3% of the total biomass of the prawns, reducing to about 2,1-2,6% of the total biomass of the prawns at the end of the period, to produce harvestable prawns.

20. A method as claimed in claim 19, which includes feeding a post-larval prawn population over a first period of about 5-9 days, the post-larval prawns being fed the initial rate of about 17,5-26,3% of the total biomass of the prawns at the beginning of the period diminishing to about 11,4-17.2% at the end of the first period to produce pre-juvenile prawns.

21. A method as claimed in claim 20, which includes the step of feeding the pre-juvenile prawns over a second period of 26-31 days an amount of feed corresponding to about 4,9-12,6% of the total biomass of the prawns at the beginning of

the period, diminishing to about 3,3-6,2% of the total biomass of the prawns at the end of the period, to produce juvenile prawns.

22. A method as claimed in claim 21, which includes the step of feeding the juvenile prawns over a third period of about 10-14 weeks, preferably about 12 weeks, an amount of feed corresponding to about 2,4-4,6% of the total biomass of the prawns at the beginning of the third period, diminishing to about 2,11-2,58% of the total biomass of the prawns at the end of the third period, to produce harvestable prawns.

23. A method as claimed in Claim 12 which, includes maintaining the water temperature in the acclimation tanks, the raceways, the grow-out tanks and the water treatment installation at about 27-31°C.

24. A method for the intensive production of prawns, the method including the step of introducing prawns into one or more grow-out tanks each having a centrally positioned outlet and a bottom which slopes inwardly towards the outlet, circulating water in the tank to cause accumulation of waste matter in the vicinity of the outlet and periodically flushing a volume of water through the outlet to cause at least some of the accumulated waste matter to be flushed away.

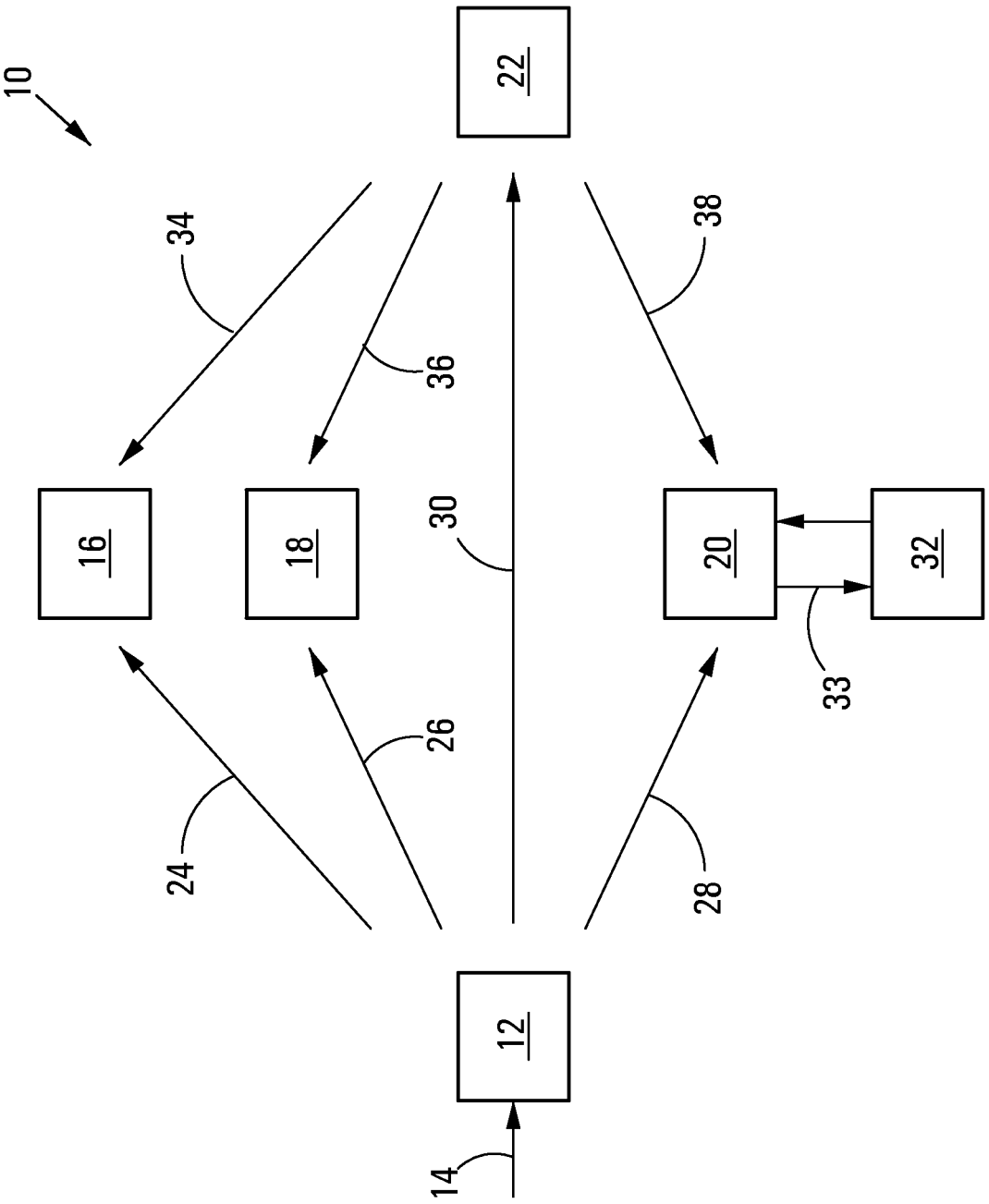


FIG 1

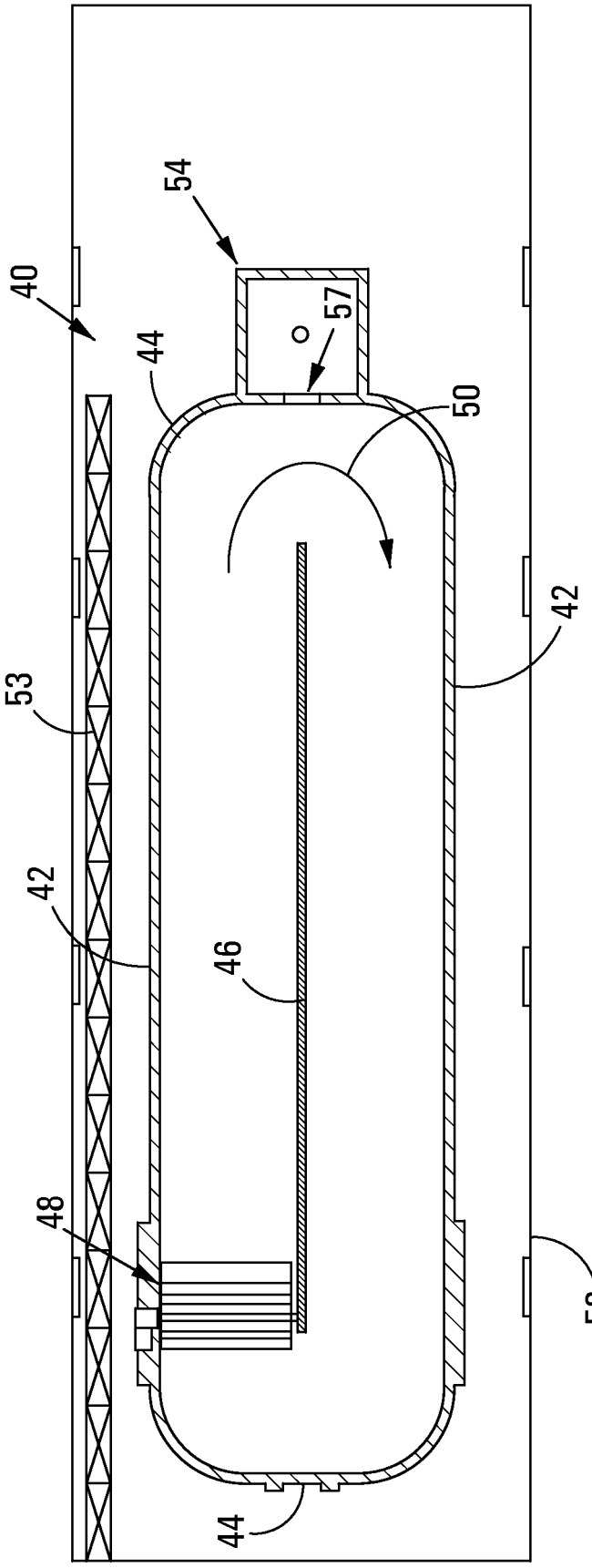


FIG 2

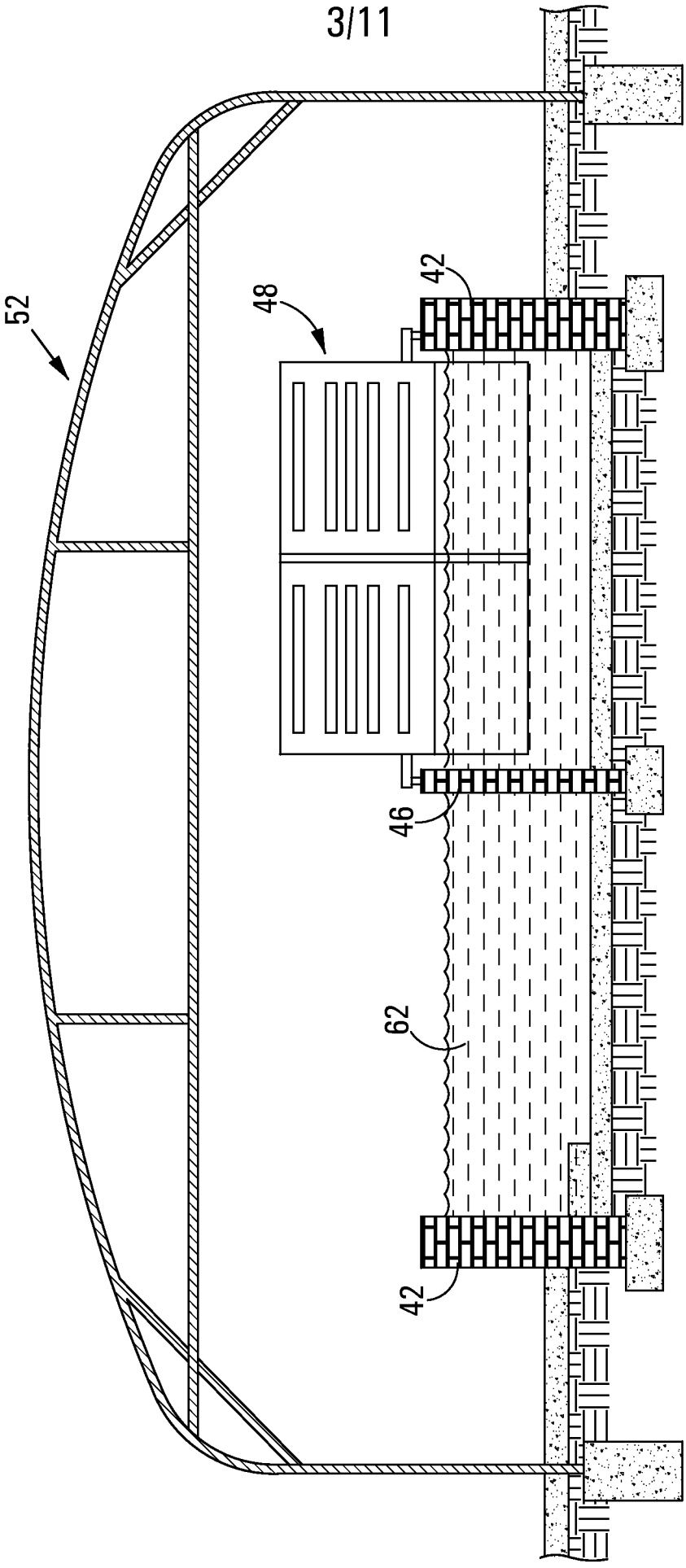


FIG 3

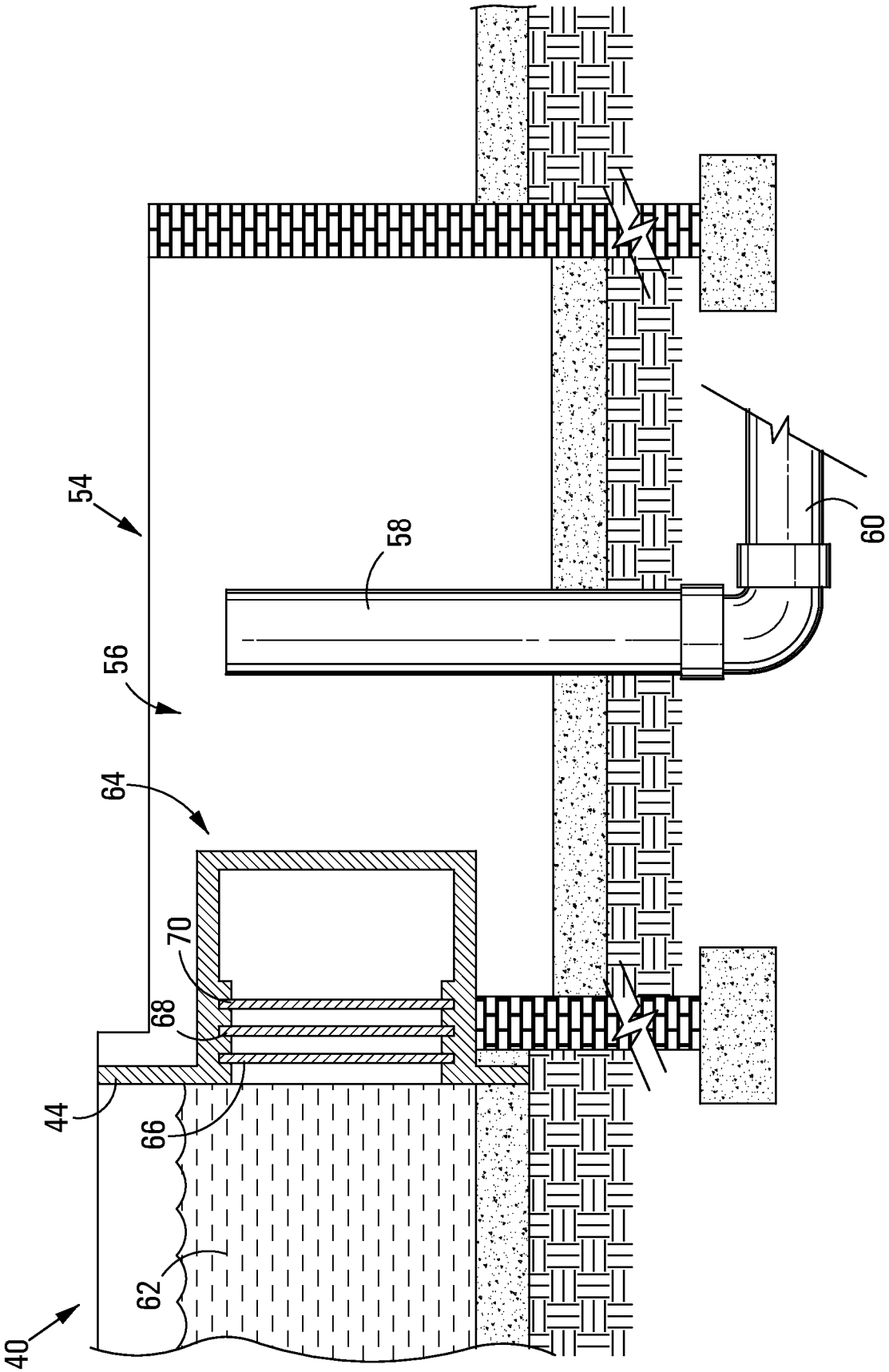


FIG 4

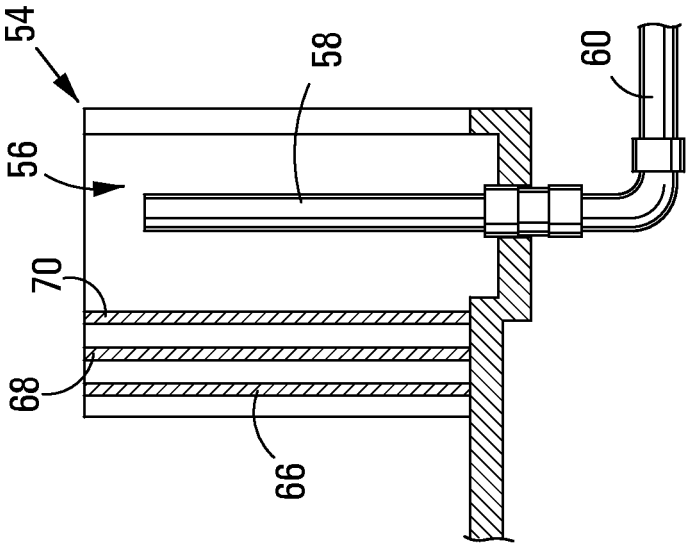


FIG 6

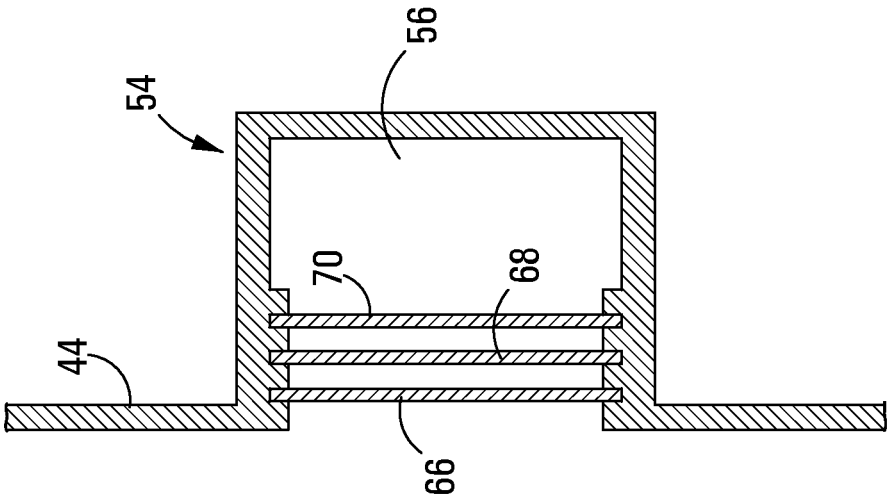


FIG 5

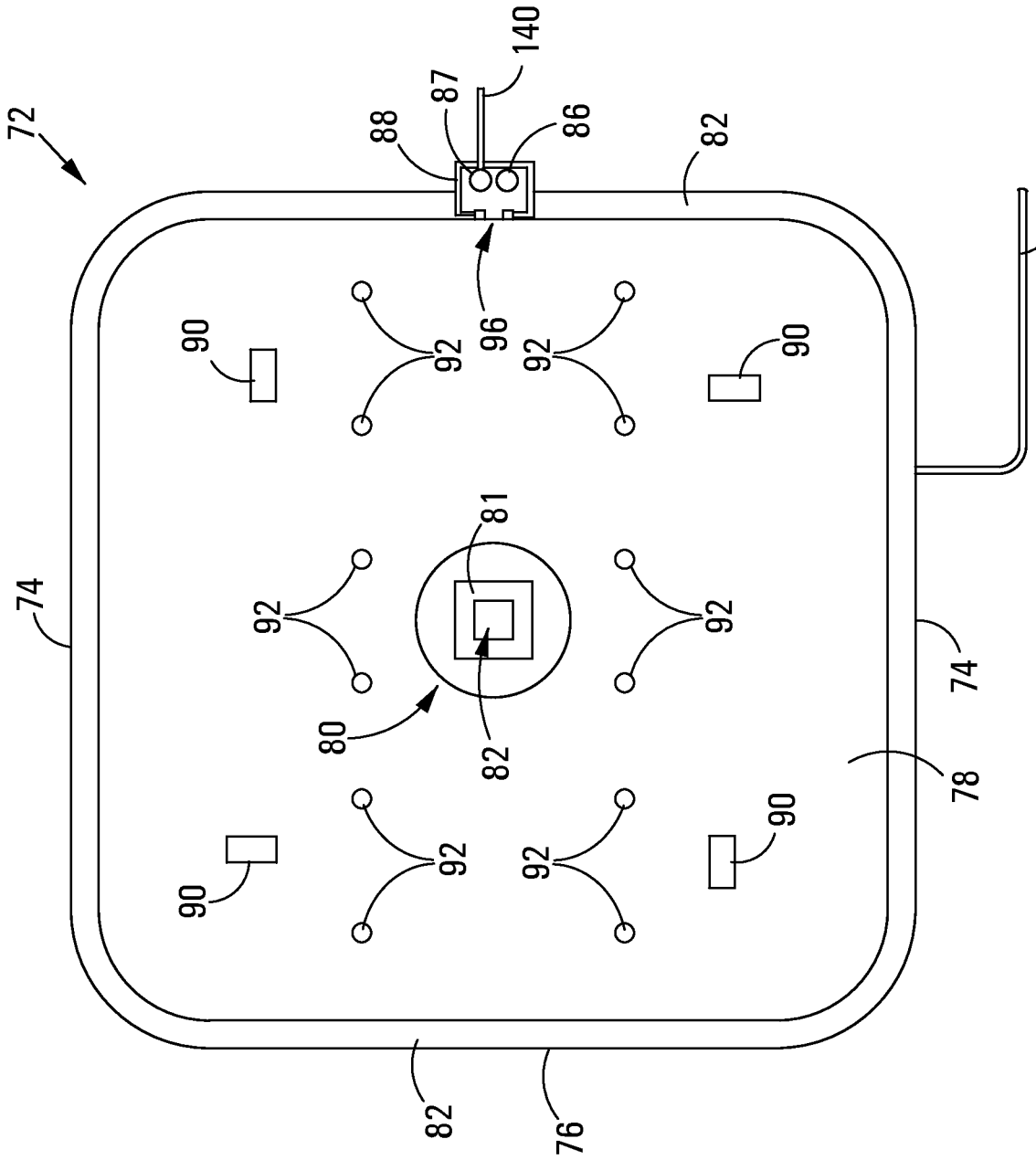

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FIG 7

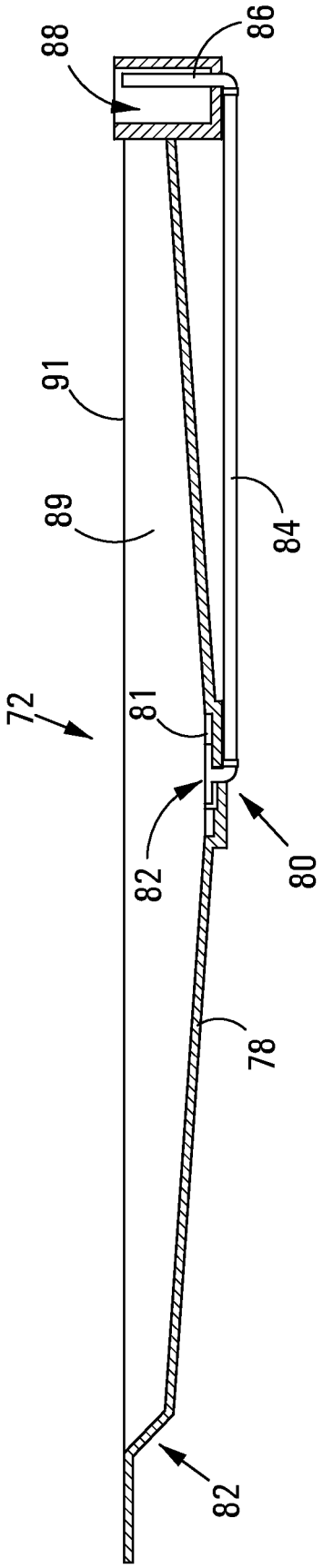


FIG 8

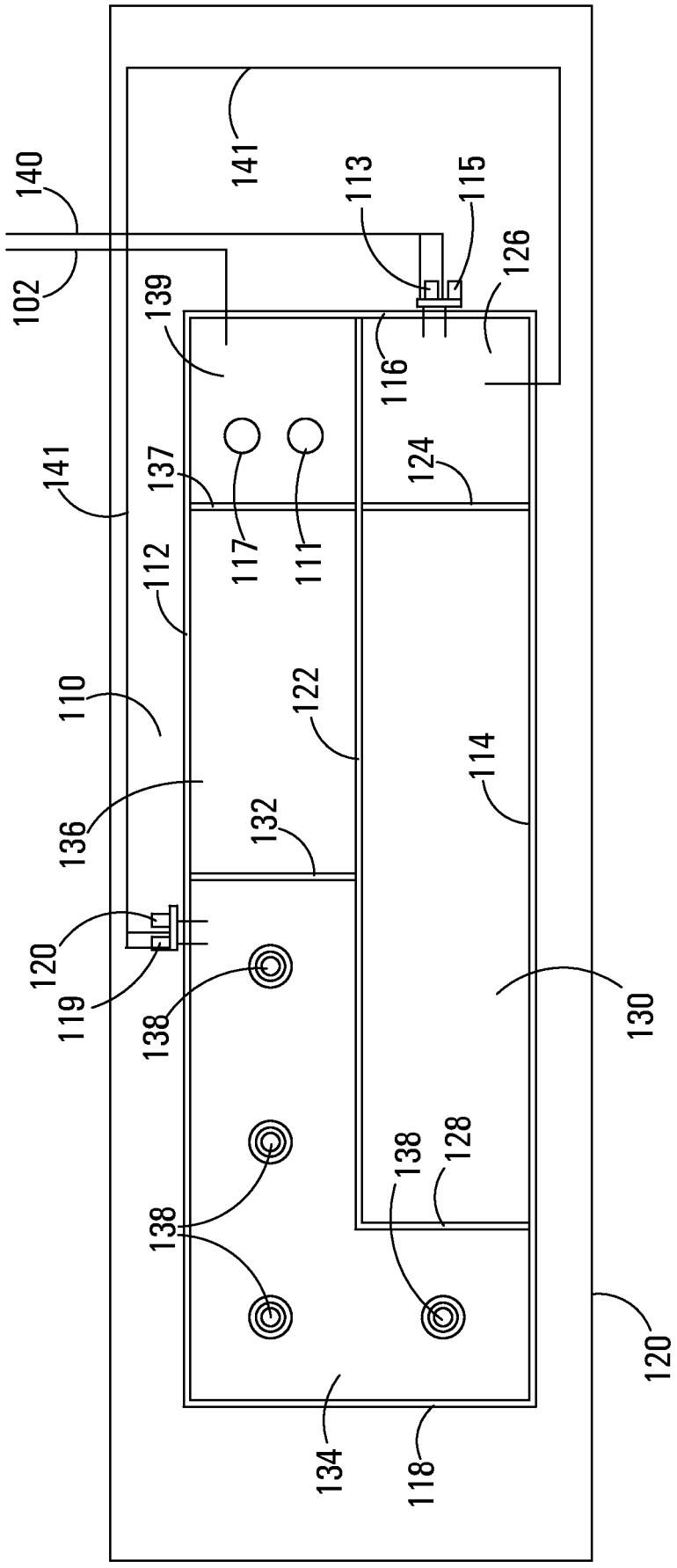

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FIG 9

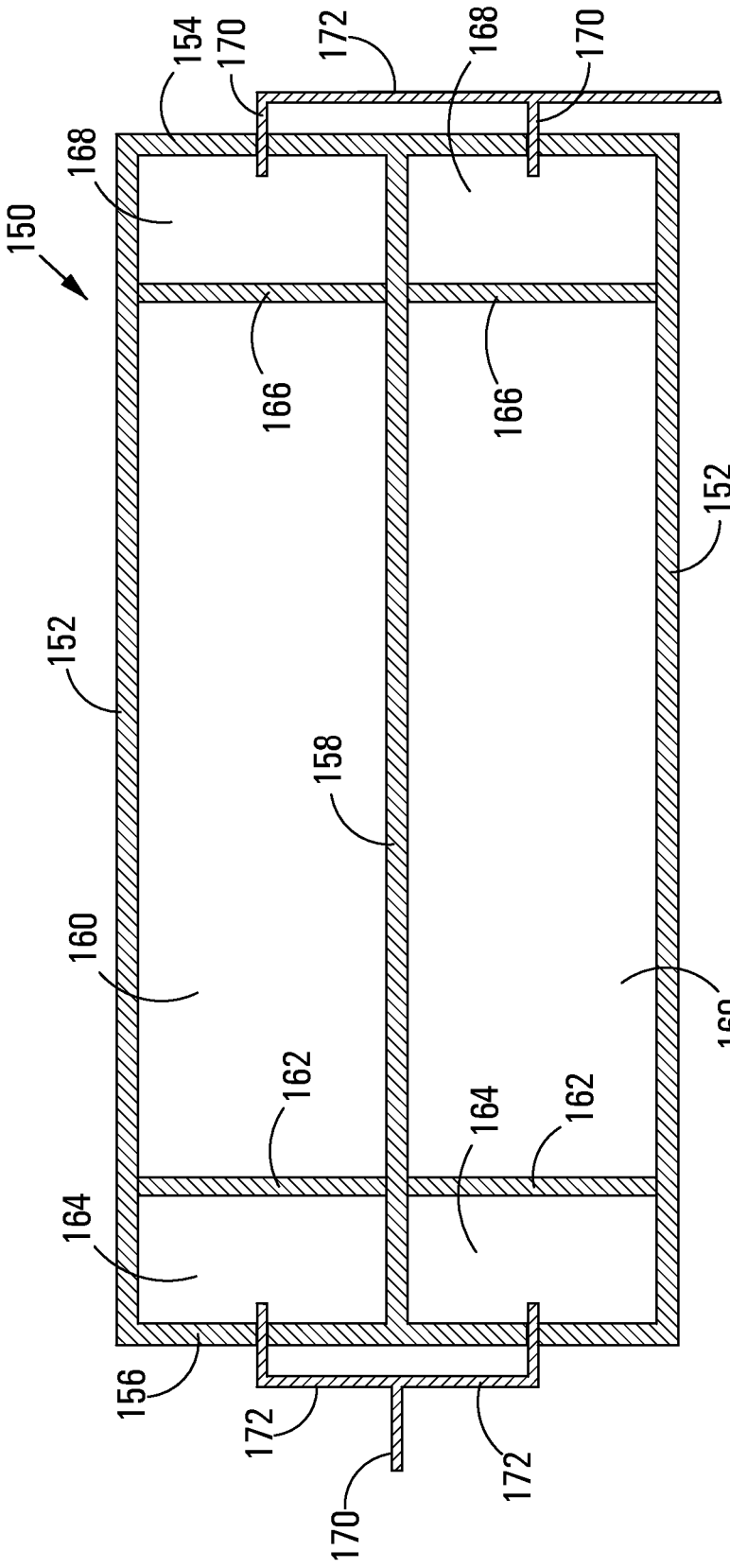

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FIG 10

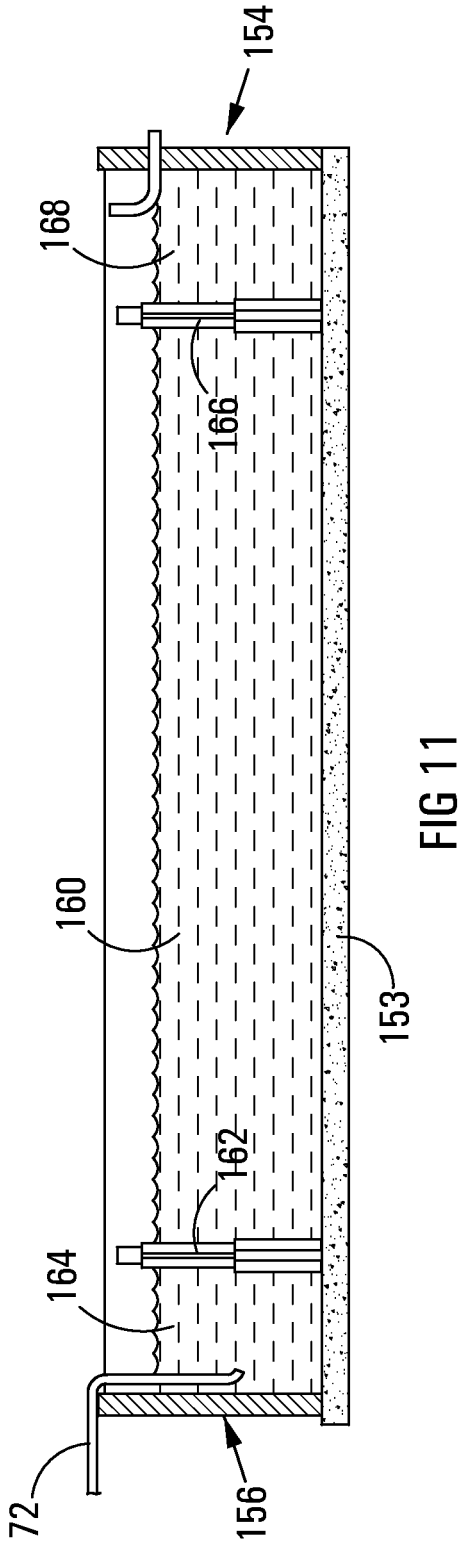

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FIG 11

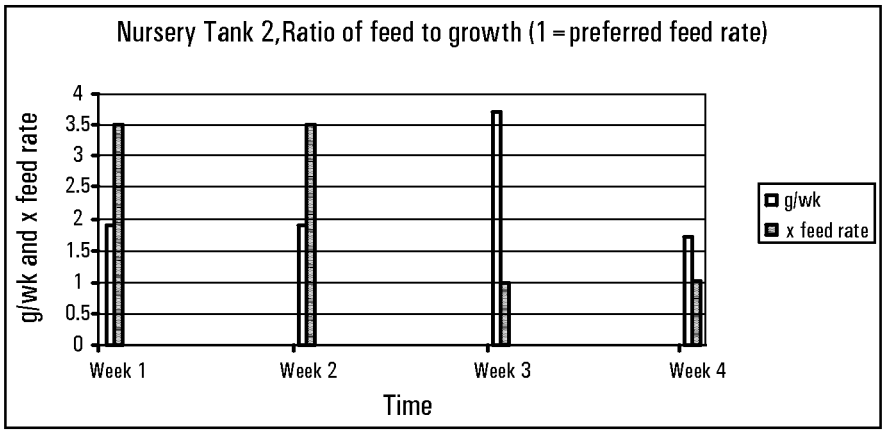

Nursery Tank 2,Ratio of feed to growth (1 = preferred feed rate)
g/wk and x feed rate
4
3.5
3
2.5
2
1.5
1
0.5
0
Week 1
Week 2
Week 3
Week 4
Time
g/wk
x feed rate

FIG 12

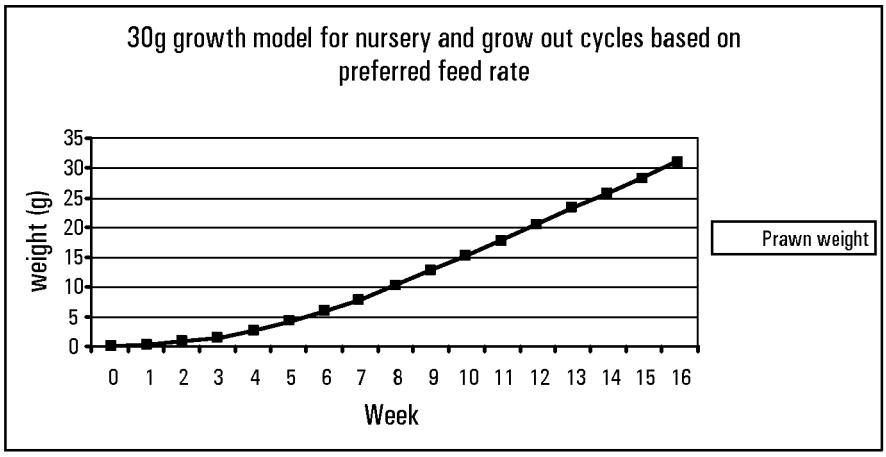

30g growth model for nursery and grow out cycles based on preferred feed rate
weight (g)
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Week
Prawn weight

FIG 13

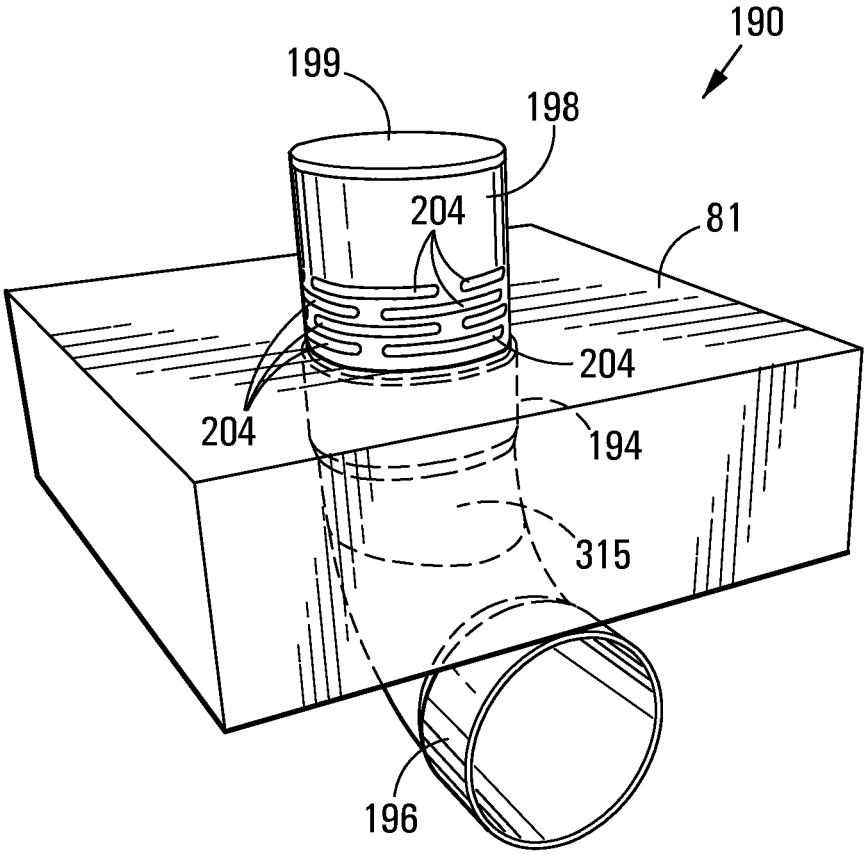

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FIG 14

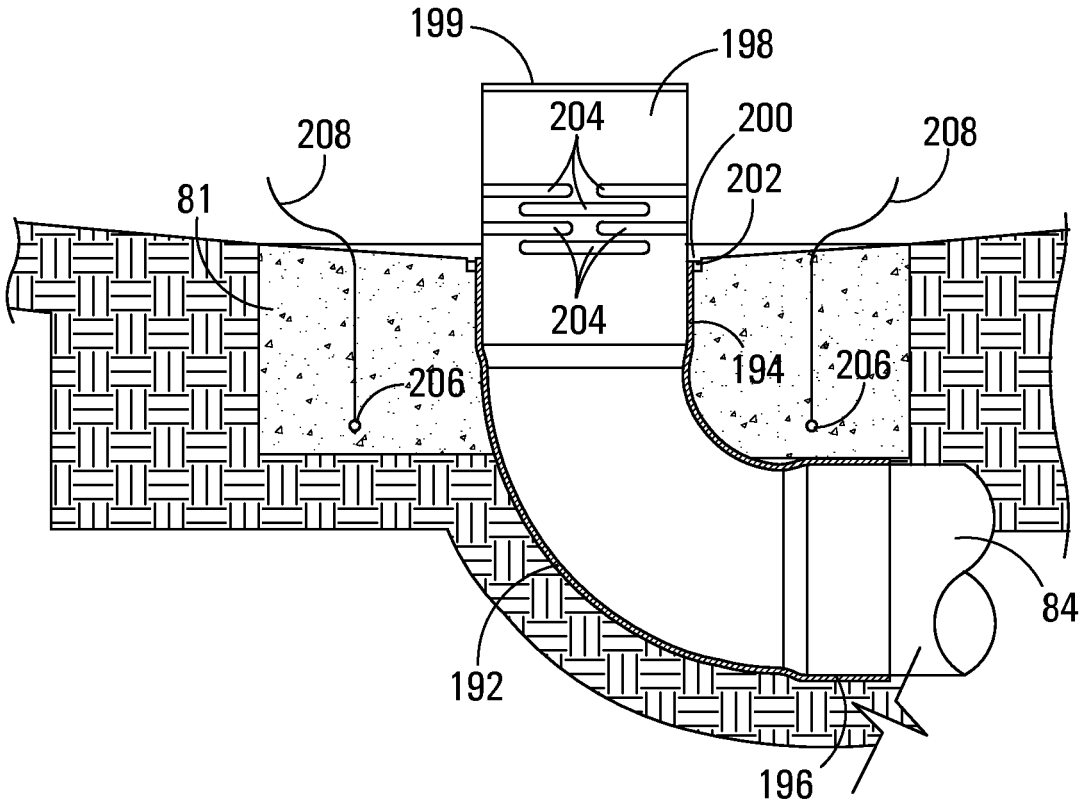

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FIG 15